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CYTOLOGICAL TESTS OF INDEPENDENT ASSORTMENT AMONG HETEROMORPHIC CHROMOSOME PAIRS IN *DROSOPHILA MELANOGASTER**

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Mendel's second law, the law of independent assortment, states that when a number of pairs of hereditary factors are present, the pairs assort independently of each other. At the microscopic cellular level, the chromosomes are the bearers of these factors. Since this is the case, it should be readily possible to demonstrate that if pairs of contrasting alleles assort independently of each other, likewise so should the paired chromosomes on which these alleles are located. Yet evidence in support of this law, through cytological studies of the behavior of the chromosomes from parents to offspring in paralleling Mendel's factors, is far from being either numerous or conclusive.

Carothers (1913) described the relationship between the behavior of the X chromosome and that of the dyads of an unequal tetrad which occurred in the primary spermatocytes of the male orthopteran *Brachystola magna.* With the X chromosome of the male as a basis of comparison, she selected three hundred cells at random and found that the respective dyads assorted with the X chromosome in approximately a 1:1 ratio. In 1917, working with two genera of Acrididae (Orthoptera), Carothers described a number of instances in which the two homologous chromosomes differed morphologically from one another and as a pair were also distinguishable from the other chromosome pairs. The homologues of several pairs were traced through anaphase I and found to segregate at random in regard to both the X chromosome and each other, and presumably to the other eight pairs of chromosomes, thus demonstrating the Mendelian expectancy of random assortment. A few years later she made a number of matings whereby she could make a direct comparative analysis between the chromosomal constitution of the parents and that of the offspring, with respect to three heteromorphic pairs (Carothers, 1921). Due to the limited number of offspring obtained, however, no valid conclusions could be drawn on a statistical basis as to the manner in which the chromosome pairs were assorting.

King (1923) described the behavior of six heteromorphic chromosome pairs through anaphase I in 224 primary spermatocyte cells of *Pseudotrimerotropis thalassica.* Tracing the assortment of the six pairs in relation to the X chromosome and to each other, King found that the dyads and the X chromosome were assorting completely at random.

Thus, although the random assortment of homologous chromosomes has been well verified as to their segregation in both primary and secondary spermatocytes, documentation of the assortment of homologous chromosomes from parent to offspring has never been effected to the extent required for statistical analysis.

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The purpose of the present study was (1) to investigate cytologically the distribution of heteromorphic chromosome pairs from parent to offspring, first considering two pairs and then three pairs of chromosomes simultaneously, and (2) to determine whether the distribution among these pairs was completely random, thus satisfying Mendel's second law at the chromosomal level.

TABLE 1

Presence vs. absence of inversion loops in the salivary gland chromosomes when considering two heteromorphic chromosome pairs simultaneously

Inversion loop	X and II*	X and III*	II and III
Absent in			
Both	47	52	62
Only one	38	49	67
Only other	45	36	44
Neither	34	40	53
Total	164	177	226
Chi-square	2.6828	3.8135	5.4690
Probability	0.50–0.30	0.30–0.20	0.20–0.10

*Females only.

MATERIALS AND METHODS

The three stocks of *Drosophila melanogaster* selected for this study are symbolized by j92, g20, and h50. Each stock is homozygous for an inversion not present in the other two. (These stocks are listed in the Bloomington, Indiana stock list [Dros. Info Serv. 30, 1956], where stock g20 is listed as containing cn^2 and InCyR; however, these were not present in the stock received here.)

Stock j92 has a homozygous inversion in the X chromosome designated as In49. The inversion breaks occur between $4D_7$ and $4E_1$ and between $11F_2$ and $11F_4$. Phenotypically, stock j92 can be distinguished by the markers yellow (y) and vermilion (v) on the X chromosome and brown (bw) on the second chromosome.

Stock g20 has a homozygous inversion in the second chromosome designated as InCyL. The inversion breaks occur between $22D_1$ and $22D_2$ and between 33F and $34A_1$. Both markers of g20, black (b) and purple (pr), are located on this chromosome.

Stock h50 has a homozygous inversion in the third chromosome designated as sepInLR. This is a pericentric inversion which phenotypically "separates" the wings. As this inversion was not listed by Bridges and Brehme (1944), the exact location of the inversion was not known. However, from a study of the banding pattern, the inversion breaks occur at approximately 74C and 90E. This stock has two markers, pink peach (p^p) and radius incompletus (ri), both located on the third chromosome. The viability of these flies is considerably lower than that of the other two stocks and a great deal of care is needed to maintain the stock.

To obtain two heteromorphic chromosome pairs in each of three different stocks, protocols (1), (2), and (3) were used. Protocol (4) was used to obtain a stock heteromorphic for three chromosome pairs. In the latter protocol only those genotypes are listed which were involved in the subsequent crossings.

(1) Protocol involving stocks j92 and g20, resulting in the X and second chromosome pairs being heteromorphic:

$$P_1 \quad \frac{y\ In49\ v}{y\ In49\ v} \quad \frac{bw}{bw} \ \text{♀♀} \times \frac{+}{+} \quad \frac{b\ InCyL\ pr}{b\ InCyL\ pr} \ \text{♂♂}$$

$$F_1 \quad \frac{y\ In49\ v}{+} \quad \frac{bw}{b\ InCyL\ pr} \ \text{♀♀} \times \frac{y\ In49\ v}{+} \quad \frac{bw}{b\ InCyL\ pr} \ \text{♂♂}$$

F_2 female larval offspring to be classified.

(2) Protocol involving stocks j92 and h50, resulting in the X and third chromosome pairs being heteromorphic:

$$P_1 \quad \frac{y\ In49\ v}{y\ In49\ v} \quad \frac{+}{+} \ \text{♀♀} \times \frac{+}{+} \quad \frac{sepInLR\ ri\ p^p}{sepInLR\ ri\ p^p} \ \text{♂♂}$$

$$F_1 \quad \frac{y\ In49\ v}{+} \quad \frac{sepInLR\ ri\ p^p}{+} \ \text{♀♀} \times \frac{y\ In49\ v}{+} \quad \frac{sepInLR\ ri\ p^p}{+} \ \text{♂♂}$$

F_2 female larval offspring to be classified.

(3) Protocol involving stocks g20 and h50, resulting in the second and third chromosome pairs being heteromorphic:

$$P_1 \quad \frac{b\ InCyL\ pr}{b\ InCyL\ pr} \quad \frac{+}{+} \ \text{♀♀} \times \frac{+}{+} \quad \frac{sepInLR\ ri\ p^p}{sepInLR\ ri\ p^p} \ \text{♂♂}$$

$$F_1 \quad \frac{b\ InCyL\ pr}{+} \quad \frac{sepInLR\ ri\ p^p}{+} \ \text{♀♀} \times \frac{b\ InCyL\ pr}{+} \quad \frac{sepInLR\ ri\ p^p}{+} \ \text{♂♂}$$

F_2 male and female larval offspring to be classified.

(4) Protocol involving stocks j92, g20, and h50, resulting in the X, second, and third chromosome pairs being heteromorphic:

$$P_1 \quad \frac{y\ In49\ v}{y\ In49\ v} \quad \frac{bw}{bw} \ \text{♀♀} \times \frac{+}{+} \quad \frac{b\ InCyL\ pr}{b\ InCyL\ pr} \ \text{♂♂}$$

$$F_1 \quad \frac{y\ In49\ v}{+} \quad \frac{bw}{b\ InCyL\ pr} \ \text{♂♂} \times \frac{+}{+} \quad \frac{b\ InCyL\ pr}{b\ InCyL\ pr} \ \text{♀♀}$$

$$F_2 \quad \frac{y\ In49\ v}{+} \quad \frac{bw}{b\ InCyL\ pr} \ \text{♂♂} \times \frac{y\ In49\ v}{+} \quad \frac{b\ InCyL\ pr}{b\ InCyL\ pr} \ \text{♀♀}$$

$$F_3 \quad \frac{y\ In49\ v}{y\ In49\ v} \quad \frac{b\ InCyL\ pr}{b\ InCyL\ pr} \quad \frac{+}{+} \ \text{♀♀} \times \frac{+}{+} \quad \frac{+}{+} \quad \frac{sepInLR\ ri\ p^p}{sepInLR\ ri\ p^p} \ \text{♂♂}$$

$$F_4 \quad \frac{y\ In49\ v}{+} \quad \frac{b\ InCyL\ pr}{+} \quad \frac{sepInLR\ ri\ p^p}{+} \ \text{♀♀} \times \frac{y\ In49\ v}{+} \quad \frac{b\ InCyL\ pr}{+} \quad \frac{sepInLR\ ri\ p^p}{+} \ \text{♂♂}$$

F_5 female larval offspring to be classified.

The flies of each preliminary cross were raised at 24°C, whereas those of the final crosses, i.e., those crosses producing the larvae which were to be classified, were raised at 18°C. In these latter crosses, the parents were transferred every two or three days in order to avoid crowded culture bottles.

Each larva was first placed in a drop of saline solution on a slide and classified as to sex. The glands were dissected in aceto-orcein and were subsequently transferred to another slide containing a drop of aceto-orcein with Janus Green B (Cordeiro, 1957) and covered with a coverslide. The chromosomes were spread using a roller.

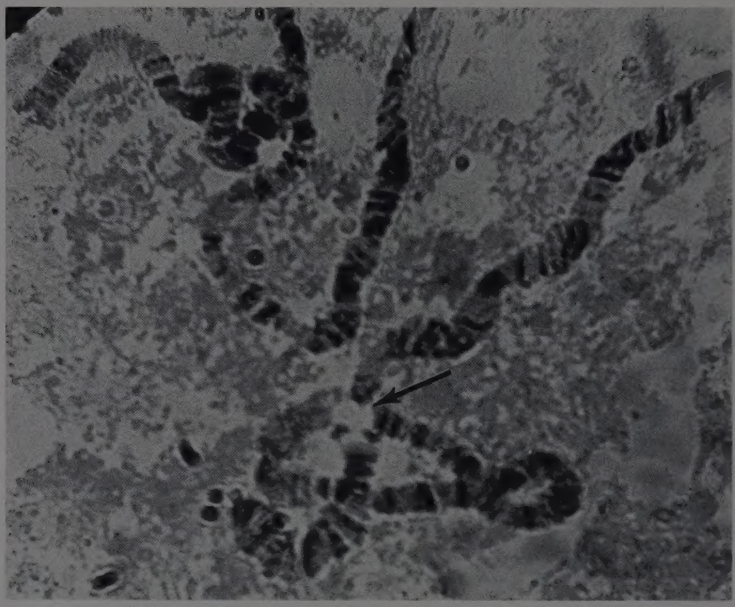

FIGURE 1. Photomicrograph of cell in which the X chromosome is heterozygous for the inversion designated as In49. Arrow indicates point of synaptic partner exchange. ×1440.

In a cursory examination, each preparation was scanned to record whether three, two, one, or no inversion loops were present. During a second and more thorough study of the slides, the chromosomes and their corresponding inversions, if present, were identified.

RESULTS AND DISCUSSION

The choice of *Drosophila melanogaster* for this study was prompted mainly by four considerations: (1) each chromosome pair is fully synapsed in the somatic salivary gland cells, and thus homologous chromosomes of one pair cannot be mistaken for those of another; (2) the banding of the chromosomes is constant and thus an aberration, if present, will always occur within the same known segment of bands; (3) since it is one of the most widely studied organisms in genetics, mutants with specific types of aberrations present are easily obtainable for experimentation and study; and (4) it is an ideal organism for genetics in that the life cycle is very short, the matings are easily controlled, offspring are produced in great numbers, even in pair matings, and there are only four pairs of chromosomes present.

Although all three inversions were quite large, I did not feel sufficiently versed in the reading of the chromosome band pattern to attempt the detection of homozygous inversions in the synapsed chromosomes. Instead, the chromosome pairs were grouped on the basis of whether inversion loops were present or absent. Thus, the larvae were grouped into four classes when two pairs of chromosomes were being studied, and into eight classes when all three pairs were involved.

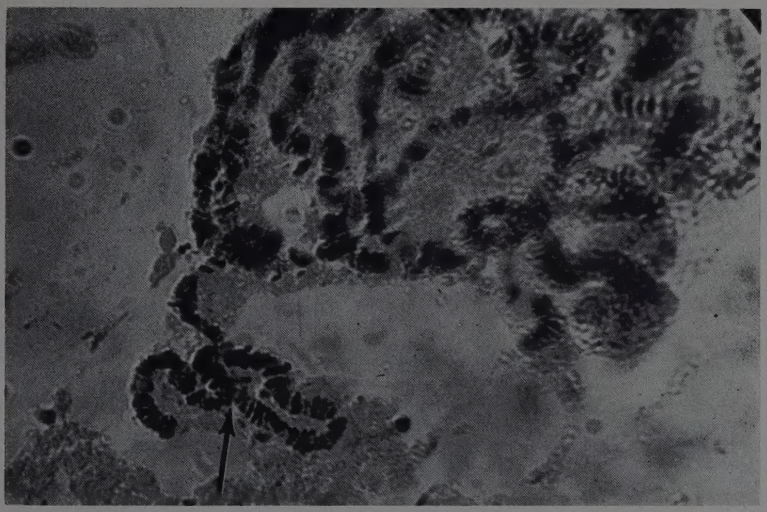

FIGURE 2. Photomicrograph of heterozygous inversion in the left arm of chromosome II, designated as InCyL. Arrow indicates point of synaptic partner exchange. ×1020.

With two pairs of chromosomes assorting independently the four classes of larvae should theoretically fall into a 1:1:1:1 ratio. With three pairs of chromosomes involved, the ratio becomes 1:1:1:1:1:1:1:1.

In the crosses respectively involving heteromorphic chromosome pairs X and II, X and III, and X, II, and III, only the females were classified as to the distribution of the chromosomes since in males the XY mechanism would permit but one class to appear with respect to the first pair of chromosomes.

Of the four final crosses, that between the F_1's from j92 crossed with g20 produced the best results from the statistical viewpoint of probability (see column

TABLE 2

Presence vs. absence of inversion loops in the salivary gland chromosomes when considering three heteromorphic chromosome pairs simultaneously

Inversion loop	X, II, and III*
Absent in X	
Absent in	
Both II and III	38
Only one	35
Only other	26
Neither	23
Present in X	
Absent in	
Both II and III	36
Only one	34
Only other	29
Neither	22
Total	243
Chi-square	8.8847
Probability	0.30–0.20

*Females only.

TABLE 3

Classification of offspring as to sex in a random sample from each of the four final crosses

Sex	X and II	X and III	II and III	X, II, and III
Male	182	199	105	215
Female	164	177	121	243
Total	346	376	226	458
Chi-square	0.9364	1.2872	1.1328	1.7118
Probability	0.50–0.30	0.30–0.20	0.30–0.20	0.20–0.10

TABLE 4

Segregation of the two homologues of heteromorphic chromosome pair III with respect to each other and to the other chromosome pairs

Inversion loop	With X	With II	With X and II	Total
Present	76	97	100	273
Absent	101	129	143	373
Total	177	226	243	646
Chi-square	3.5310	4.5310	7.6090	15.4800
Probability	0.10–0.05	0.05–0.02	<0.01	<0.01

Heterogeneity chi-square: 0.1955, probability 0.70–0.50.

TABLE 5

Segregation of the two homologues of heteromorphic chromosome pair II with respect to each other and to chromosome pairs X and III

Inversion loop	With X	With III	With X and III	Total
Present	79	106	114	299
Absent	85	120	129	334
Total	164	226	243	633
Chi-square	0.2196	0.8672	0.9260	1.9352
Probability	0.70–0.50	0.50–0.30	0.50–0.30	0.30–0.05

Heterogeneity chi-square: 0.0778, probability 0.80–0.70.

for X and II, table 1). This was probably due to the fact that both inversions are quite large and the corresponding inversion loops are readily seen even under low power. Therefore, few problems of interpretation arose with respect to this cross.

The results of the F_1 crosses between j92 and h50, and g20 and h50 are very similar (column for X and III and column for II and III, table 1). In both instances, the frequencies of the two classes where the inversion loop is present in chromosome III are lower than the other two classes. This is probably due to the fact that the inversion in chromosome III is pericentric and for that reason is somewhat hard to identify since the chromocenter usually is surrounded to some extent by the mass of chromosomes. Very infrequently, the chromosomes have been forced by the pressure of smearing to the side of the chromocenter and only in such an instance is the inversion, if not also forced over, clearly seen.

The results of the final cross involving three heteromorphic chromosome pairs simultaneously (table 2) have a fairly random distribution, except that again, classes which involve the presence of an inversion loop in chromosome pair III have consistently lower frequencies than the other classes.

Since the possibility exists that the presence of the inversions in themselves may have caused the segregation to deviate toward one class or the other, it was

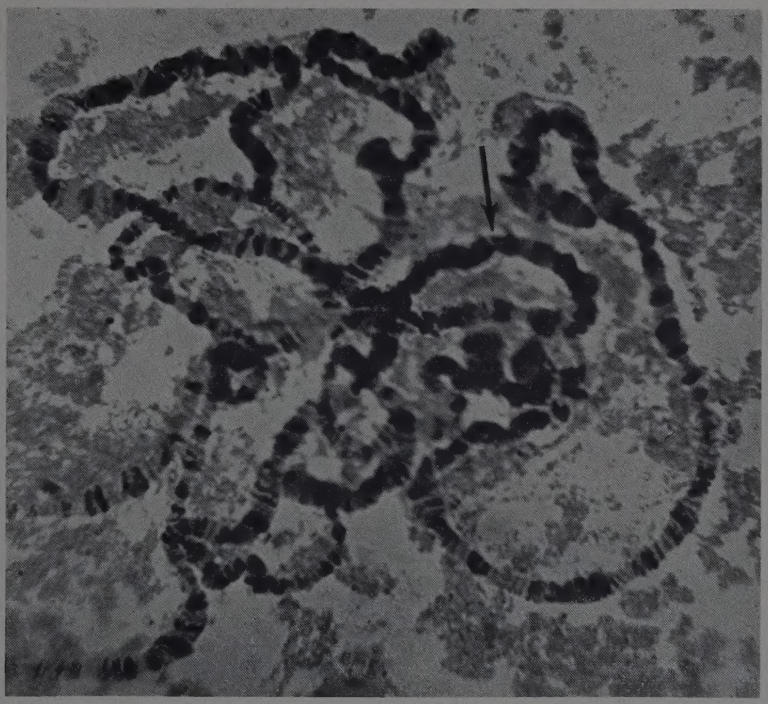

FIGURE 3. Photomicrograph of heterozygous inversion in chromosome III. This pericentric inversion, indicated by arrow point, is designated as sepInLR. ×1060.

considered necessary to ascertain if such were the case. As there is in *Drosophila* a "built-in" mechanism by which one can determine whether normal segregation is taking place, i.e., the XY mechanism, a random count was made, classifying male and female offspring in each of the final crosses. The results of this simple test are given in table 3. It may be seen that on the basis of a 1:1 expectation there is no significant deviation in any of these crosses.

Since the frequencies of the classes where the inversion loop is present in chromosome pair III are consistently low, it was thought necessary to find out whether the two homologues of this chromosome pair were segregating in a 1:1 ratio with respect to each other. In two of the three crosses, it was found that there is a significant deviation from expectation, in the direction of too few with a loop present, indicating that a 1:1 segregation of the two homologues was not taking place (see table 4). A chi-square heterogeneity test was also made, the results of which indicate that all three crosses are homogeneous with respect to the deviating segregation of chromosome pair III.

One reason mentioned above for this departure from the expected ratio may be the difficulty in detecting pericentric loops. An alternate explanation is that the marker genes and/or the inversion itself are somehow affecting the gametes. According to Bridges and Brehme (1944), the marker genes on chromosome III, i.e., p^p and ri, do not have any reduction of viability attributed to them. Therefore, assuming that the inversion is reducing the viability of those gametes which contain it, it can be shown that the inversion classes without loops will always exceed the inversion classes with loops by a factor of $4x^2/n^2$, where x/n is the

proportion of "lowering of gamete effectiveness" due to the presence of an inversion.

The values of x/n computed from table 4 are 1.4 percent, 1.2 percent, and 1.3 percent, for columns 1, 2, and 3, respectively. Therefore, the viability of those gametes which receive the inversion in chromosome III may be reduced by approximately 1.3 percent.

A similar series of chi-square tests (table 5) was made in regard to the two homologues of chromosome pair II. In these tests, there were no significant deviations from the expected ratio, and it may be assumed that these homologues are segregating at random with respect to each other. A chi-square heterogeneity test was also made, the results of which indicate that the three crosses are consistent with each other.

Thus, although the homologues of chromosome pair III were not segregating as expected, the deviation caused by this behavior was not great enough in any of the four crosses to affect the over all picture of independence in assortment.

SUMMARY

1. A cytological study of the salivary gland chromosomes of 810 larvae of *Drosophila melanogaster* was made in respect to the distribution of members of heteromorphic chromosome pairs from parents to offspring, as a test of Mendel's second law at the chromosomal level.

2. Inversions in the X, second, and third chromosomes were used as cytological markers.

3. The location of the inversion breaks of the sepInLR inversion in the third chromosome, previously unknown, are at approximately 74C and 90E.

4. Three F_1 stocks were developed, each with two heterozygously inverted chromosome pairs. The F_2 larvae of these stocks were studied. The results on the basis of chi-square tests showed no significant deviation from expectation based on the assumption that independent assortment was taking place.

5. A fourth stock was developed which was composed of flies heterozygous for all three inversions. The larvae from this heterozygous stock were also classified. As with the other three crosses, the results did not deviate significantly from those expected, assuming Mendel's second law was operating.

6. The two homologues of the third chromosome pair did not segregate in a 1:1 ratio with respect to each other, thus differing from the behavior of the X and second chromosome pairs. A possible explanation for this deviation is that the eggs and/or sperm which receive this inversion are not as viable as those which receive the noninverted third chromosome, i.e., a position effect.

ACKNOWLEDGMENTS

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THICKNESS OF LOESS IN CLARK COUNTY, ILLINOIS

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In 1942, Guy D. Smith published the result of a comprehensive investigation of loess thickness, distribution, texture, etc. throughout the state of Illinois. His map showing the thickness and distribution of loess was mainly the compilation of data gathered by previous workers throughout the state. In certain areas, especially along the Wabash River, the available data were limited, and the map for this region was necessarily generalized.

The present study was conducted in Marshall and Casey Quadrangles, Clark County, Illinois, as a special project for the Agronomy Department of the University of Illinois and was under the direction of Dr. R. T. Odell. Clark County is in east-central Illinois and is bounded to the east by the Illinois-Indiana state line and the Wabash River (fig. 1). This study was made to obtain more detailed information on the distribution and thickness of loess deposits of a limited area west of the Wabash River. The investigation was intended to show the relationship of loess to the Wabash River bottoms and to note what effect, if any, the Shelbyville moraine of Wisconsin age has on the loess.

Sixty holes were drilled with a one-inch screw auger through the loess into the underlying material. Since the loess thickness changes more rapidly adjacent to the bluffs west of the Wabash River than at a greater distance from the river, the borings were spaced more closely near the river to get more detailed information on this critical area. Also, since loess consists predominantly of silt size material, the contact between the loess and the underlying material was chosen at the first appearance, in appreciable quantity, of sand or larger fragments. To avoid errors in thickness due to postglacial erosion or deposition, bore holes were limited to flat, undisected divides. Even so, the authors feel that some of the bore holes were contaminated. Thus, locations and thicknesses of all stations were plotted on a topographic base map and are reproduced on figure 2, but the thicknesses that have been contoured on figure 2 do not take into account obviously questionable values.

Topography and Drainage

The topography and drainage of the area is controlled by the Wabash River. The region is in the middle youthful stage of the erosion cycle. All the streams are tributaries of the Wabash River and are cut about 100 ft below the general level of the divides. The larger tributaries, near their confluences with the Wabash River, have developed fairly extensive flood plains and have reached maturity. Near the headwaters, the streams are youthful and expanding on to the undissected uplands. The stream pattern is dendritic. The Shelbyville moraine cuts across the northwestern corner of the area and stands about 100 ft above the rest of the county. It has the typical knob and kettle topography of a terminal moraine.

Glacial Geology

Casey and Marshall Quadrangles were covered by the ice during the last two stages of the Pleistocene glaciation. Illinoian till was deposited over all of Clark County, altering the preglacial topography. Following the Sangamon interglacial period of weathering, the ice again advanced during the Wisconsin stage, its farthest extent being marked by the Shelbyville moraine. In addition to the till constituting the Shelbyville moraine, Wisconsin deposits also include a sheet of outwash beyond the moraine and loess deposits which cover almost the entire

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county. The loess covers the weathered surface of the Illinoin till and is interbedded with the till and outwash of the Shelbyville moraine, part of the loess being older and part younger than the till. Subsequent erosion has removed the loess from the youthful stream valleys.

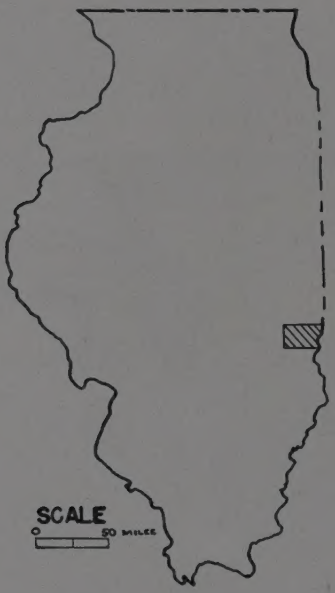

FIGURE 1. Index map showing location of area studied.

History of the Wabash Valley (Fidler, 1948)

In pre-Pleistocene times, the ancestral Wabash River followed approximately the same course as the present Wabash River and laid down extensive gravel deposits. Subsequent erosion during early Pleistocene times cut a bedrock channel over a hundred ft below the present river level and left the gravel as isolated patches on the upland. The deep valley system was developed well before Illinoian glaciation; Kansan till beneath Illinoian drift has been identified within some of the buried valleys. Illinoian glaciation covered all of Clark County and filled the Wabash River Valley with drift. Sangamon erosion removed nearly all of the till from the river valley.

In Wisconsin time the Wabash River acted as a sluiceway for the melt water from the ice front to the north. At about the time the Shelbyville moraine was constructed, a large volume of outwash collected in the Wabash River Valley. Many bedrock features were buried in the alluvium. During later Pleistocene, the ancestral Lake Erie, Lake Maumee, overflowed at the present location of Fort Wayne and poured clear water down the Wabash River. This flood of clear water extensively eroded the older Shelbyville aggradational surface, developing a lower flood plain and leaving the Shelbyville surface as isolated upland remnants. The present floodplain was constructed below the Maumee surface during late Pleistocene or Recent times.

Distribution and Thickness

Loess of varying thickness has been found to cover all the flat uplands of Clark County. The thickness and distribution, however, is closely related to the Wabash River. This is well demonstrated on figure 2. The thickest loess deposits, on the bluffs immediately west of the river, are all over 100 in. in depth. One sample taken on the edge of the bluff totals only 44 in. of loess, but is probably affected by post depositional erosion. The thickness decreases very rapidly away from the bluff and is from 40 to 60 in. in the central part of the area mapped. The loess-depth lines are therefore closely spaced near the bluff but become farther apart toward the center of Clark County.

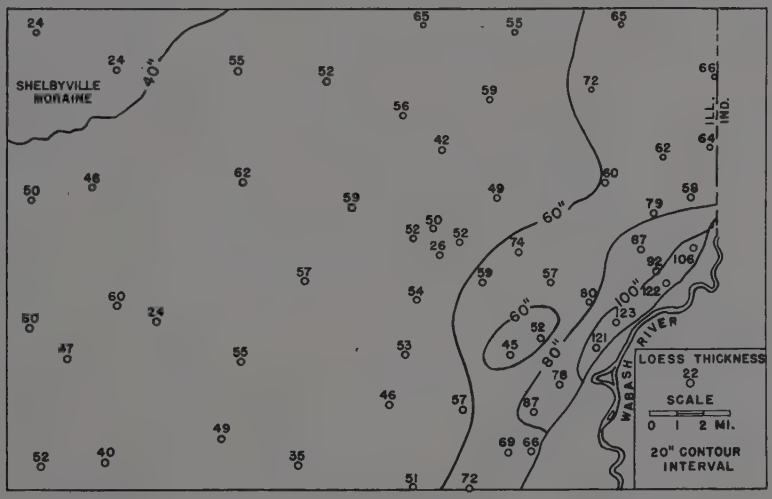

FIGURE 2. Contour map showing thicknesses of loess and location of bore holes.

Following the method devised by Smith (1942), the loess depth is plotted against the distance from the bluff on three cycle semi-log graph paper as shown in figure 3. The thinning of loess away from the bluff can be expressed by the equation: $Y = 87 - 36 \text{ Log } X$. As pointed out before, several anomalous thicknesses occur within zones of otherwise uniform loess thicknesses. There are several possible explanations for this. 1) There is a possibility of human error in determining the loess-till contact. 2) Various organisms burrow beneath the surface and tend to mix the loess and till fragments together. 3) The work covered a much smaller area and was necessarily more detailed; therefore, inconsistencies and inaccuracies of depth not readily apparent in Smith's work are relatively more important in a smaller area. 4) The loess was not deposited on a completely level surface. Thus, protected areas would tend to collect more loess than other areas. 5) The presence of the Shelbyville moraine had some effect on increasing the thickness toward the moraine instead of toward the Wabash River. Twenty-four in. of post-Shelbyville loess were recorded in two borings on top of the moraine. It is reasonable to assume that at least this much post-Shelbyville loess is present directly in front of the moraine and that this loess gets thinner in a southerly direction.

Age

The loess lies on top of weathered Illinoian till and, therefore, is Wisconsin in age. Leighton and Willman (1950) state that Wisconsin loess in Illinois may be divided into two parts, a lower Farmdale loess and an upper Peorian loess of Iowan, Tazewell, Cary and perhaps Mankato age. The Farmdale loess has a distinctive pinkish-gray color in contrast to the buff colored Peorian loess and can only be recognized when the overlying Peorian loess is calcareous and when the Farmdale is thick enough to be uncontaminated with materials from below. Since the Peorian loess is leached and the Farmdale is apparently thin in this

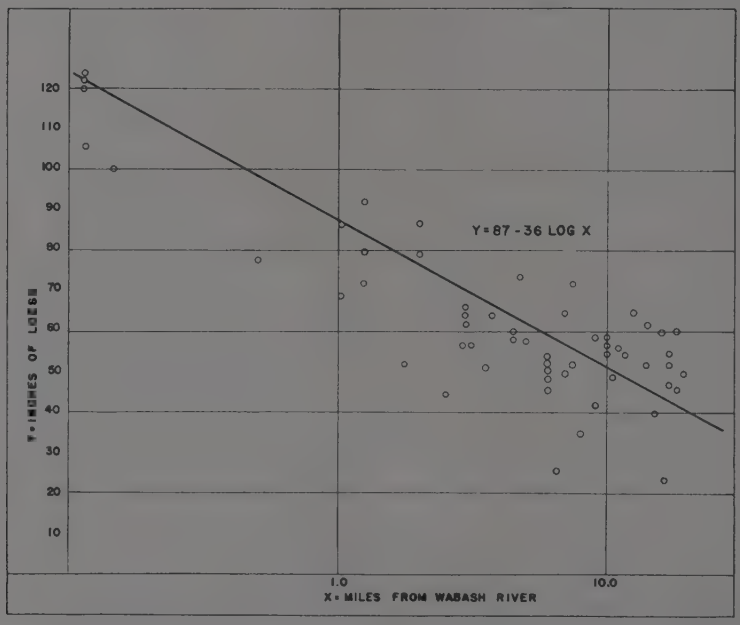

FIGURE 3. Graph showing relationship between thickness of loess and distance from Wabash River.

area, it is very difficult to recognize the Farmdale here. Farmdale loess has been identified by the authors in only one bore hole and if present in other holes, was not apparent. Recent borings by J. B. Fehrenbacher (personal communication from R. T. Odell, 1959) show that from 7 to 17 in. of Farmdale loess do occur in borings he has made in Clark County.

Texture

Although no mechanical analyses were run, it was observed that the loess near the Wabash River bluffs is composed of coarser silt, with a smaller percentage of clay minerals and a larger percentage of sand than the loess farther away from the river.

Origin

It was originally believed that loess was desposited by water. T. C. Chamberlin (1897) proposed that loess was carried by wind from outwash plains and valley trains which were filled with silt derived from the continental glaciers. This origin has been strengthened by subsequent observation. Smith (1942) showed almost incontravertable evidence that the thickness, texture, calcium carbonate content, and degree of weathering of loess are very closely related to glacial drainageways. The present investigation shows a very distinct thickening of loess toward the Wabash River and a less obvious but still apparent thickening near the Shelbyville moraine. This study, therefore, is an additional bit of evidence that loess is of wind blown origin being derived in the main from glacial outwash. This represents the first systematic and detailed study of the western side of any Illinois river with regards to thickness of loess.

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ALGAL PHOTOSYNTHESIS AS MEASURED BY ABSORPTION OF RADIOACTIVE CARBON FROM WATER

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INTRODUCTION

Photosynthesis is perhaps the most fundamental process in nature. The green plant, using the energy of sunlight, is able to combine the carbon dioxide of the air with water from the soil and from them produce carbohydrates. The energy needed for the activities of most living matter comes directly or indirectly from these carbohydrates.

While in the past photosynthesis has been studied only sporadically, a new era of investigative work began with the availability of radioactive carbon. Marine physiologists and limnologists, especially, became greatly interested in oceanic and lake productivity.

This investigation is concerned with algal photosynthesis in Urschel's Quarry. The Steemann-Neilsen C^{14} method (1957) was employed for measuring the absorption of radioactive carbon by the algae, with a modification which allowed for comparison between the C^{14} concentration and yield and the duration of exposure and yield. The C^{14} method is very useful when applied to oceanic and lake waters because it is one thousand times more sensitive than other methods. Although a

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great deal of study has been conducted on oceanic productivity, this method has been little used in fresh waters. Therefore, more testing of this method in fresh water, as in this study, is needed.

I wish to acknowledge the assistance of Dr. Verduin, who served as adviser and suggested the problem. The Department of Biology, Bowling Green State University, furnished the necessary facilities for this study. The C^{14} was supplied gratis by Dr. Mikihiko Oguri, of the University of Hawaii. This work was supported in part by an Atomic Energy Commission grant: AT(11–1)-536.

METHODS

Between July, 1958 and January, 1959 water samples from Urschel's Quarry were collected and inoculated with radioactive carbon. They were subsequently suspended under water, on the same site from which they were collected, for a certain period of time. These samples were then analyzed in the laboratory and tested for radioactivity on an end-window Geiger-Müller counter. From these data average photosynthetic values were computed.

In order to measure algal photosynthesis, a modification of the Steemann-Nielsen C^{14} method was employed. This provided for comparison between the C^{14} concentration and the observed yield.

A set of three 35 ml dropper bottles was used, one of which was covered with masking tape and used as a control. Into each bottle were placed 25 ml of water from Urschel's Quarry. One ml containing 0.5 μc of radioactive carbon was then added to each bottle. The three bottles were tied with plastic tubing at 0.1 and at 0.6 meter depths as follows: the control (dark) bottle and one clear bottle were both suspended at 0.6 m depths while the other clear bottle was suspended at 0.1 m. The experiments were begun at 1100 o'clock and terminated at 1400 each day. Each sample was filtered on a Millipore filter and immediately washed with 25 ml of distilled water containing one drop of IKI (acetic) killing agent. The filters were allowed to dry at room temperature, and then were taken to an end-window Geiger-Müller counter for counting. The Geiger-Müller counter was manufactured by Nuclear of Chicago Incorporated and had an efficiency of 0.00415 for C^{14}.

In September, 1958, this method was modified and three sets of three 35 ml dropper bottles were used. While the basic procedure remained unaltered, both the duration of exposure and the concentration of C^{14} were changed.

First, the three sets were submerged under water at 0800 o'clock and one set was brought to the laboratory at 1100, at 1400, and at 1700, respectively.

Second, the concentration of radioactive carbon in each set was varied while the duration of exposure was kept constant. The three sets were suspended from 1100 to 1400. The first set contained 0.25 μc, the second set, 0.5 μc, and the third set, 2.0 μc of radioactive carbon. These two modifications were employed alternately each week.

Radioactive carbon, in the form of $Na_2C^{14}O_3$ solution in ampoules, was furnished by Maxwell S. Doty's research laboratory of the University of Hawaii. Each ampoule contained five μc of C^{14}. The stock solution of radioactive carbon was prepared as follows: tap water and a 35 ml dropper bottle were placed in a 250 ml beaker and boiled for 20 min. This was done in order to sterilize the bottle and kill the microorganisms present in the tap water. Nine ml of boiled water were added to the sterilized bottle. An ampoule of C^{14} (5μc) was then placed in the bottle and broken immediately. The bottle was stoppered and shaken vigorously. This represented the stock solution of radioactive carbon.

SAMPLE COMPUTATION

Some of the data recorded during August, 1958 are shown in table 1. In order that the rate of carbon uptake be computed correctly, the following conditions should be present. First, $C^{14}O_2$ should be incorporated in organic compounds

only through photosynthesis. Second, the rate of assimilation of $C^{14}O_2$ should be the same as that of $C^{12}O_2$. Third, $C^{14}O_2$ should not be lost by respiration taking place simultaneously with photosynthesis. Fourth, no organic matter should be lost by excretion (Steemann-Nielsen, 1957). Although none of these conditions could be absolutely assured, the difference between the control bottle and the clear bottle was assumed to represent photosynthesis. Steemann-Nielsen postulated that correction factors ranging from 5 to 155 percent are applicable, depending on the ratio of photosynthesis to respiration. Because the ratio of photosynthesis to respiration is not known, and the influence of bacterial synthesis also is not known, the computations in the present study did not include such correction factors.

TABLE 1

Sample data recorded during August, 1958

Date	Depth (m)	Time in	Time out	Count/min	Methyl Orange Alk.
8/8/58	0.1	1100	1400	92	4.225 (mEq of base)
	0.6			87	or
	Control			56	4225 (μmole of CO_2
8/12/58	0.1	1100	1400	106	3.844 (mEq of base)
	0.6			88	or
	Control			58	3844 (μmole of CO_2
8/20/58	0.1	1100	1400	95	3.970 (mEq of base)
	0.6			93	or
	Control			25	3970 (μmole of CO_2

The photosynthetic rates were computed as follows: from table 1, no. 1, the count of the control bottle was subtracted from the count of the clear bottle. The difference represented the C^{14} absorbed due to photosynthesis.

$$\begin{array}{r} 92 \text{ count/min} \\ -56 \text{ count/min} \\ \hline 36 \text{ count/min} \end{array} \tag{1}$$

This value was divided by the product of $(0.00415 \times 1.1 \times 10^6)$, where 0.00415 was the efficiency of the Geiger-Müller counter, and 1.1×10^6 was the disintegrations per min contained in 0.5 μc of C^{14}. This yields the fraction of the C^{14} absorbed by the phytoplankton.

$$\frac{36}{0.00415 \times 1.1 \times 10^6} = 79 \times 10^{-4} \tag{2}$$

Formula two was multiplied by the value of total CO_2 in the water as indicated by the titratable base (Methyl Orange Alkalinity). This yields micromoles of CO_2 per liter of water. Methyl orange alkalinity tests were run each day as described by Welch (1952). For example: if the titratable base is 4.225 mEq per l and the pH is about 8.2, then bicarbonate predominates and each calcium ion will be associated with $2HCO^-_3$ ions; hence, total CO_2 is 4225 μmole per l.

$$79 \times 10^{-4} \times 4225 = 33.4 \ \mu\text{mole } CO_2/\text{l}. \tag{3}$$

Formula three in turn was divided by the number of hours of exposure to give micromoles of CO_2 per liter of water per hour of time.

$$\frac{33.4}{3} = 11.1 \ \mu\text{mole } CO_2/\text{l/hr}. \tag{4}$$

RESULTS AND DISCUSSION

Computations were made for each experiment performed. Average values of micromoles of CO_2 absorbed per liter of water per hour were found for 0.1 and 0.6 m. An overall average value of micromoles of CO_2 absorbed per liter of water per hour was also computed. The same procedure was used for 0.25 μc, 0.5 μc, 2.0 μc and also for three-hr, six-hr, and nine-hr exposures. The results found during the summer of 1958 revealed an average hourly yield of 13 μmole/l at 0.1 m and 11 μmole/l at 0.6 m. Data for the period between September, 1958 and January, 1959 are tabulated in tables 2 and 3.

TABLE 2

Average micromoles of CO_2 per liter of water per hour with respect to C^{14} concentration recorded from September, 1958 to January, 1959

μcuries per 25 ml	At 0.1 m	At 0.6 m	Overall average
0.25	16.2	13.2	14.7
0.5	13.5	11.7	12.6
2.0	13.9	11.8	12.8

TABLE 3

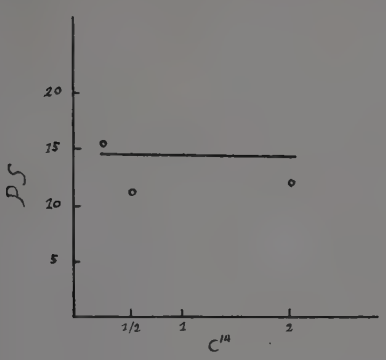
Average micromoles of CO_2 per liter of water per hour with respect to time of exposure recorded from September, 1958, to January, 1959

Duration From-To	At 0.1 m	At 0.6 m	Overall average
0800–1100	19.6	10.9	15.2
0800–1400	21.4	14.5	17.9
0800–1700	19.1	13.1	16.1

From these data certain definite conclusions could be derived. First, the summer data indicated that photosynthesis was more active on the average at the surface of Urschel's Quarry water than at the 0.6 m depth. Some variations, however, were encountered during the course of the experiments. It was noticed that during the brightest summer days photosynthesis was more active at the 0.6 m depth. Excess light appears to inhibit photosynthesis at the surface layer, while at 0.6 m, better photosynthetic conditions occur. Also, the control bottle occasionally gave high counts (see table 1). This was probably due to microbial growth in the stock bottle. A stock bottle was used for three consecutive days, and bacteria introduced on the first day might make considerable growth. Using a dark bottle provides a correction for such growth in the stock solution. The actual C^{14} as fixed in the stock solution was of the order of one percent of that present; hence, it represented a negligible error in the estimate of C^{14} concentration.

The data in table 3 indicate that the uptake of carbon dioxide was not influenced by the C^{14} concentration. In figure 1, the C^{14} concentration per bottle is plotted against the observed yield estimates at 0.1 m. The yield estimate is shown to be relatively independent of the C^{14} concentration. A similar graph for the 0.6 m data would appear essentially like that in figure 1, but the points would be near the value of 12 on the ordinate.

As indicated from the data of table 4, slightly higher yields were obtained during an exposure of six hr. This may be attributable to better light supplies during midday (Doty, 1957). Also, the yields obtained during a three-hr exposure and a nine-hr exposure are identical. It is believed that respiration occurring actively during the afternoon hours compensated for the higher yield obtained during the midday hours. In figure 2, the duration of exposure was plotted



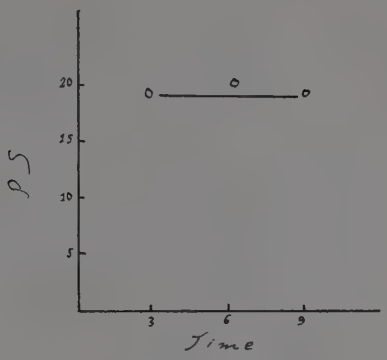


FIGURE 1. Relationship between C^{14} concentration (μc/25 ml) and photosynthesis (micromoles of CO_2 absorbed per liter of water per hour) at the 0.1 m depth.

FIGURE 2. Relationship between duration of exposure (in hours) and micromoles of CO_2 absorbed per liter of water per hour at the 0.1 m depth.

against the observed yields. Photosynthesis, represented by the straight line, is shown to be relatively independent of the duration of exposure within the range of time studied. A similar graph for the 0.6 m data would appear essentially like that in figure 2, but the points would be near the value of 12.5 on the ordinate. These data show that in situations where a nine-hr exposure is necessary to provide a significant count per minute, such exposures will yield results equally valid with those of shorter exposure.

TABLE 4

Comparison of average μmoles of CO_2 per liter per hour under ice with summer data, 1958

	At 0.1 m	At 0.6 m	Overall average
Winter	14.3	8.3	11.2
Summer	13.0	11.1	12.0

TABLE 5

*Photosynthesis per square meter per day for various waters as compared with that of Urschel's Quarry**

Place	Photosynthesis M. Mole
Lake Erie	512†
Gaynor Lake	450
Walvis Bay (Ocean)	316‡
Boulder Lake	255
Sandusky Bay	200
Base Line Lake	170
Urschel's Quarry	168
Beasley Lake	162
Haydens Lake	152
Kansas Ditches	151
Allens Lake	145
Kossler Lake	122

*Verduin, 1956.
†Verduin, 1959.
‡Steemann-Nielsen, 1957.

TABLE 6

Average μmoles of CO_2/μliter per hour in summer and winter, 1958

	At 0.1 m	At 0.6 m	Overall average
Summer	1.32	1.13	1.22
Winter	0.78	0.45	0.61

Table 4 reveals that photosynthesis was as active during the winter months as it was during the summer months. This, then, provides evidence that aquatic plankton is actively photosynthesizing during the winter. Light penetration data obtained during the winter months showed that the amount of light at the 0.6 m depth is about 5 percent of the surface light. In spite of the dim light at 0.6 m, phytoplankton is shown to photosynthesize actively during the winter months at this depth.

In table 5, a comparison is presented between the photosynthetic rate per square meter in Urschel's Quarry and that of other waters as measured by different methods. It is evident that the productivity of Urschel's Quarry as determined by C^{14} methods is similar to the value reported for other aquatic environments.

Table 6 shows the hourly average micromoles of CO_2 photosynthesized per unit phytoplankton volume during the summer and winter, 1958. The plant volumes were determined by Cowell and Sechriest, who kindly provided the data (unpublished) for this computation.

Since photosynthesis per liter was almost identical (table 4) during the summer and winter of 1958, it took twice the volume of winter phytoplankton to photosynthesize as much CO_2 as the summer phytoplankton did. The value of 0.78 is close to the value of 1.2 determined by Verduin for Urschel's Quarry phytoplankton studied with the pH method of determining CO_2 change, during the winter of 1957–58 (unpublished data). Also, yields varying from 0.2 to 1.4, with an average yield of 0.5 at optimal light conditions, were reported by Verduin (1956) for Lake Erie. These values are closely similar to the value of 0.61 for Urschel's Quarry winter phytoplankton.

SUMMARY

The Steemann-Nielsen C^{14} method was employed to measure algal photosynthesis in Urschel's Quarry. It was adapted to permit comparison between the C^{14} concentration and yield, and the duration of exposure and yield. It was found that the C^{14} concentration did not influence the observed yield importantly. While slightly higher yields were obtained during a six hr exposure, the yields obtained during a three and a nine hr exposure were almost identical. It is postulated that the favorable light conditions during the midday hours influenced the photosynthetic rate during this time. Also, active respiration during the afternoon hours may account for the identical yields obtained with three and nine hr of exposure. In general, the yield obtained was independent of duration of exposure within the range of time studied.

Photosynthesis was found to occur actively during the winter months in the Urschel's Quarry phytoplankton.

Results of the present investigation are generally in agreement with the other work conducted on lake and oceanic productivity.

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NOTES ON THE CURCULIONOIDEA II

20. A contribution to the knowledge of the Curculionoidea

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Since the publication of the last notes, additional information on several species has come to light. Notes on some additional species have also been included. I am indebted to Miss Rose E. Warner of the National Museum, who made additional examples of *Piscatopus* available several years ago, and to Dr. Fred Truxal of the Los Angeles County Museum, who made library facilities available. (ELS) refers to E. L. Sleeper Collections; DGK, to David G. Kissinger; (USNM), to United States National Museum.

BRENTIDAE

Two examples of the scarce *Ulocerus sordidus* Sharp, described from northwestern Panama, were collected at Santo Domingo, Costa Rica, V–15–46, ELS, (ELS), from beneath the bark of logs near the edge of the beach. A single pair was found. This species was previously recorded, with some question, from Mexico (Blackwelder, 1947).

Dr. David G. Kissinger has sent a pair of *Taphroderes mexicana* Sharp from Coyame, Catemeco in Southern Vera Cruz, Mexico, VI–54, DGK, (ELS). With these was an undescribed *Abactrus* which I take great pleasure in naming after the collector.

Abactrus kissingeri, new species
Figures 4 and 9

Female.—Elongate, very cylindrical; derm black, with elytra deep reddish black; glabrous and feebly alutaceous. *Rostrum* slender, feebly dilated apically, more than half as long as prothorax (7:11), feebly curved; smooth, minutely punctate and finely transversely wrinkled in front of antennal insertion, more coarsely punctured behind antennal insertion, the latter at basal third. Antennae rather long and loosely articulated; first segment nearly as long as following three combined, segments 2–6 rounded, 7–8 larger, oval and slightly compressed, 9–10 quadrate, 11 elongate and acuminate, as long as preceding 2 segments combined (3:1:1:1:1.4:1.3:1.4:1.4:2:2:4); segments 9–11 strongly compressed, densely setose laterally only, the remaining segments with a few scattered lateral setae; all segments moderately alutaceous. *Head* flattened, triangular from dorsum, punctures of front and vertex as on base of rostrum; head constricted some distance behind eyes into a short cylindrical neck. Eyes rounded, feebly convex, finely granulate. *Prothorax* elongate (11.3:5), cylindrical in basal third then strongly compressed laterally in remaining two-thirds; a raised carina behind apical margin emarginate at middle, laterally directed posteriorly becoming evanescent in compressed lateral area; pronotum minutely punctured and with a faint groove in apical two-thirds, groove not attaining raised apical carina. *Elytra* elongate, almost 4 times longer than broad (17:4.5), striae one very deep, without strial punctures, remainder of elytra nonstriate, but with very fine, widely separated strial punctures; apical emargination broad, rather prominent. *Ventral* side very convex with a few scattered coarse punctures most of which are lateral. None of the ventral sternites caniculate or sulcate at middle; first abdominal sternite with a very feeble, shallow fovea at base between coxae, 2d abdominal sternite with a prominent, transverse oval raised area which is closely, coarsely punctured at hind margin, 3–4 subequal, together as long as fifth, fifth with a broad median transverse depression; hind margin feebly arcuate. Legs short, very robust. Femora very stout, fore a little stouter, all unarmed. Tibiae short, stout, and only about half as long as femora, fore tibiae with four acute spines at apex, middle and hind tibiae with only two acute spines. Tarsi elongate in proportion to femora and tibiae, all compressed laterally, the middle and hind tarsi more strongly so; third segment cavernous, exposing true 4th segment; fore tarsi with first segment slightly longer than second, last segment very long and slender; middle and

hind tarsi with first segment very elongate, longer than following two combined, second and third subequal, last segment long, cylindrical, as long as preceding two combined. Length from fore margin of eye to apex of elytra 5.7 mm; width of proxthorax at widest part 0.75 mm.

Holotype no. 71. Female. Coyame, Catemeco, Vera Cruz, Mexico, VI–54, DGK, (ELS). a unique.

A. kissingeri is more closely related to *A. championi* than to *A. sahlbergi*, from which it may be separated by the following key:

1. Elytra with two vague fasciae, apices yellowish and the apical emargination scarcely present. . . . . *sahlbergi* Sharp
1'. Elytra without fasciae, unicolorous; apical emargination prominent. 2
2. Pronotum without groove; pronotum and elytra without punctation; apical emargination less prominent; Panama. . . . . *championi* Sharp
2'. Pronotum with groove; pronotum and elytra with minute punctures; apical emargination very strong; Mexico. . . . . *kissingeri*, n. sp.

It would be interesting to know for certain the sex of the type of *A. championi* Sharp. Sharp states, "It is no doubt of the male sex; the antennae have much setosity on the lower surface." However, he states in the discussion following the original description with regard to the abdominal sternites, ". . . the hind margin of the prominent part porous on the middle." The latter is a characteristic of the females of both *Abactrus* and the closely related genus *Taphroderes* Schönherr. The males of all species of *Taphroderes* examined have the "porous" area divided and in a V-shape. No males of *Abactrus* have been seen.

CURCULIONIDAE

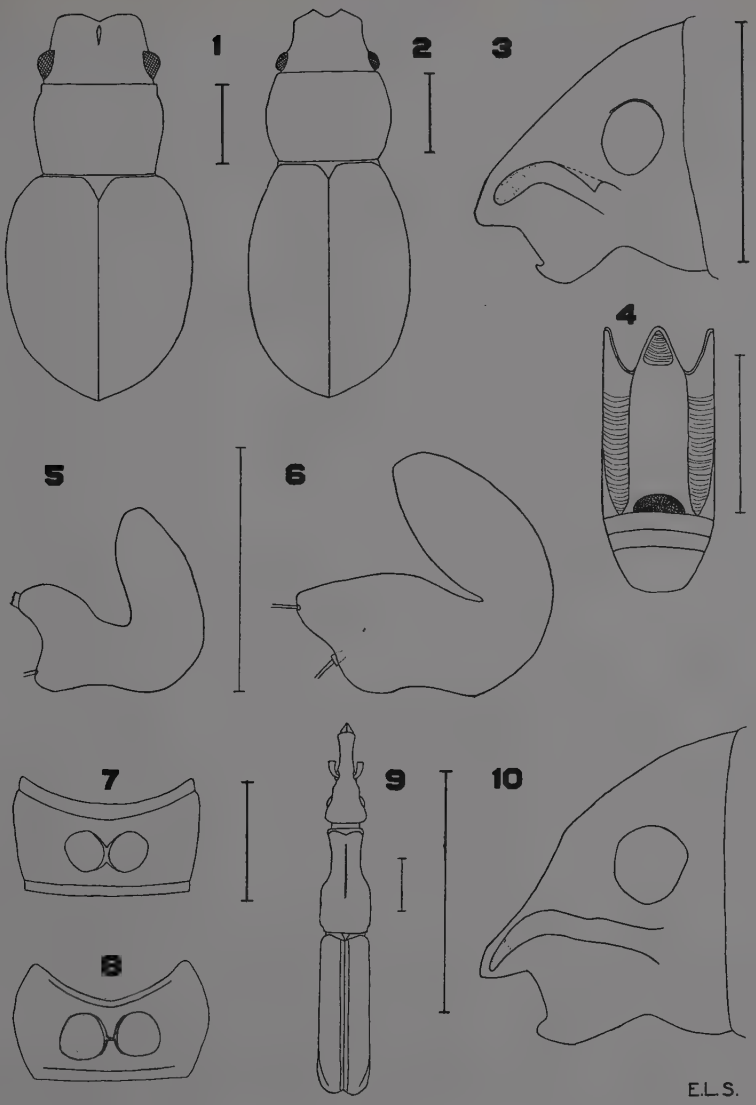
Brachyderinae

Piscatopus, new genus (Tanymecini)

Body small, elongate; vestiture consisting of overlapping scales and coarse, recumbent setae *Rostrum* short, much broader at base than long, sides convergent from eyes to apex; alae not noticeably dilated; nasal plate absent; mentum large and broad; mandibular scar conspicuous Scrobes deep, linear, directed beneath and scaly; apical half visible from dorsum, upper edge sharp ending in a prominent tooth at lower angle of eye. Scape straight, when in scrobe not surpassing a line drawn vertically through middle of eye; funicle and club together longer than scape. *Head* slightly convex, continuous with rostrum, the outline of both a feeble arc from apex of rostrum to anterior margin of prothorax; eyes very widely separated, moderately convex, lateral, prominent from above; with marginal groove on dorsal arc. Prothorax much broader than long, sides strongly arcuate, neither apex nor base constricted; ocular vibrissae present, but feeble; ocular lobes absent. Scutellum broad, flattened and triangular. Hind wings absent *Elytra* oblong, longer than broad, slightly wider than prothorax; humeral angles absent; striae with a row of punctures, 10th abbreviated, absent in basal third. *Ventral side* with fore coxae separated by one-third to one-half their width by prosternum (fig. 8), middle coxae separated by more than one-half their width, rear coxae separated by twice their width. Side pieces of mesosternum unequal, metepisternal suture not visible, metasternum between middle and rear coxae slightly longer than second abdominal segment, very broad and truncate; first abdominal suture arcuate at middle, first abdominal segment longer than 2d + 3d, 2d longer than 3d + 4th, 3d and 4th subequal, 5th a little shorter than 2d. Legs with front femora normal; all tibiae slender, anterior not denticulate within; apical spinules short and acute; fore and middle tibiae mucronate, hind tibiae with a few longer spines at inner apical angle; cotyloid surface of all tibiae terminal and scaly. Tarsi narrow, elongate, the 3d segment feebly bilobed. Claws free and divergent.

Genotype.—Piscatopus griseus, new species.

Piscatopus should be placed in the Tanymecini of the Brachyderinae next to *Elissa* Casey (1888:271). It will key to *Isodacrys* Sharp in our generic keys by virtue of the separated front coxae and the absent humeral angles. However, it is closely related to *Elissa* which does not actually have the front coxae contiguous, as indicated by Casey (1888, 271), but narrowly separated in most specimens (180 of 221 examples of *E. laticeps*) examined (fig. 7). *Piscatopus* can be separated from *Elissa* by the former's having the front coxae separated by the prosternum



1. Body outline of *Elissa laticeps* Casey, ♀, Presidio, Texas.
2. Same of *Piscatopus griseus*, n. sp., ♀, holotype.
3. Outline of lateral aspect of head and rostrum of *Piscatopus griseus*, n. sp., ♀, holotype.
4. Abdominal sternites of *Abactrus kissingeri*, n. sp., ♀, holotype.
5. Outline of spermatheca of *Yuccaborus frontalis* (LeConte), Morongo Valley, California.
6. Same of *Y. grossus* Casey, El Paso, Texas.
7. Prosternum of *Elissa laticeps* Casey, ♀, Presidio, Texas.
8. Same of *Piscatopus griseus*, n. sp., ♀, holotype.
9. Dorsal outline of *Abactrus kissingeri*, n. sp., ♀, holotype.
10. Outline of lateral aspect of head and rostrum of *Elissa laticeps* Casey, ♀, Presidio, Texas.

Figures 5 and 6, line=½ mm. Figures 1 to 4, 7 to 10, line=1 mm.

(fig. 8), the 10th elytral striae absent in basal third, lacking tumid area in front of eyes and the smaller mandibles. In *Elissa* the prosternum does not intervene between the front coxae, the 10th striae is complete, occasionally a little weak, from base to apex, a tumid area in front of eyes and has rather large conspicuous mandibles. *Piscatopus* differs from *Isodacrys* in the shorter, very broad rostrum, widely separated eyes, nonswollen front femora, and nondenticulate front tibiae.

Piscatopus griseus, new species
Figures 2, 3, and 8

Female.—Elongate-oval, strongly convex; densely clothed throughout with uniform gray scales and short coarse white recumbent setae; derm black, antennae and legs reddish brown. *Rostrum* very short and broad (3.75 long:6.2 wide); dorsum slightly convex between antennal insertion, continuous with front when fully clothed with scales, when denuded dorsum slightly concave with an elongate, narrow, rather shallow fovea and lateral carinae which are divergent from scrobes. Antennae with funicle and club somewhat longer than scape (5.7:4); scape straight, attaining middle of eye, 1st funicular segment robust, almost as long as 2d + 3d, 2d elongate, longer than 3d, 4th and 5th equal, 6th and 7th subequal, each slightly longer than 5th and gradually widening; club oval, acuminate and sparsely clothed. *Head* moderately convex; derm as on rostrum, densely closely punctured, punctures at times coalescent; eyes separated by a little less than length of prothorax at middle (5.75:6.75) moderately convex, coarsely granulated, readily visible from dorsum, circular in lateral aspect; marginal groove distinct only on dorsal arc. *Prothorax* broader than long (9.3:6.75), sides rather evenly arcuate, apical and basal margins truncate, disc feebly convex in lateral aspect; derm very minutely, densely punctured. Scutellum broad, flattened, triangular and densely scaly. *Elytra* oblong, longer than broad (19:12); striae not impressed, strial punctures small, separated by more than twice their diameter, completely obscurred by the scaly vestiture; intervals broad, flattened, subequal, confusedly punctured with minute, closely placed punctures and a single row of larger setiferous punctures, the short recumbent setae in a single row on each interval. *Ventral side* clothed as dorsum, first abdominal segment strongly convex transversely, a little shorter than 2d + 3d + 4th, (segments 4:2.7:.8:.8:2.3). Legs clothed as body. Tarsi elongate, posterior tarsi with 1st and 2d segments equal, 3d slightly longer, 4th nearly as long as preceding three; anterior tarsi shorter, first segment almost one-half longer than 2d, 3d little longer than 2d, 4th slightly longer than 1st and 2d. Claws completely free and widely divergent. Length 4.7 mm, width 2.1 mm.

Male.—Differs from the female in more slender form, the less inflated elytra, and the structure of the ventral abdominal segments; the first abdominal segments flattened laterally and a little concave at middle. Length 3.5 mm, width 1.5 mm.

Type locality.—Redford, Presidio Co., Texas, other locality, Presidio, Presidio Co., Texas.

Type material.—Holotype no. 68, ♀, Redford, Presidio Co., Texas, VII–20–45, H. F. Smith, (ELS); allotype, ♂, Presidio, Texas, X–28–44, J. H. Russell, (USNM); 4 paratypes as follows: 1 ♀, same data as holotype, 1 ♂, same data as allotype, (ELS); 1 ♂, 1 ♀, same data as allotype, (USNM). The paratypes vary little from the holotype and allotype other than by size, length 4.0–4.3 mm, width 1.8–2.0 mm.

The material from Presidio was found on the foliage of *Larrea divaricata* Cav.

Alophinae

A long series of *Lepidophorus setiger* Hamilton was found beneath recently cut beech limbs on a hillside near the entrance to Camp Wyandot, along Clear Creek, in Hocking Co., Ohio, V-27-57. The only other example known from Ohio was collected further up Clear Creeks XI–1–49, NJ & ELS, from beneath a rock.

A single example of *Plinthodes foveirostris* (Chittenden) was taken in Hocking Co. (Ash Cave), IX-11-54, R. D. Alexander and ELS, (ELS). Previous records for this weevil were from much further south in Virginia, North Carolina, and Tennessee. The single example was found late at night crawling through forest litter beneath predominantly hemlock cover.

Magdalinae

When the description of *Magdalis lecontei decepta* Sleeper was published (1955b: 158) a typographical error occurred. The heading for the description should have read "*Magdalis*

lecontei decepta, Sleeper, new subspecies." In the discussion of the subspecies it was properly noted as a subspecies. (This note has been previously sent to another journal, but in as much as a two-year period has elapsed since submission, I am adding it to this note to correct the error before a longer period elapses.)

Since the publication of the description of *Magdalis hockingensis* Sleeper (1955a: 56), a third example of this species has been collected. It is smaller than either the holotype (ELS no. 44) or paratype, measuring only 2.6 mm, width 1.0 mm. It was collected from the same tree as the paratype, and only 300 ft from the tree from which the holotype was collected. It bears the data Hocking Co., Ohio, V–27–57, ELS, (ELS).

Cryptorhynchinae

A single example of *Tyloderma foveolata* Say was collected at Mogone, Oaxaca, Mexico, III–13–46, ELS, (ELS), thus extending the range of this species much further south in Mexico than previously reported.

Two examples of *Gerstaeckeria fasciata* Pierce, known previously only from a unique type, have been collected; one specimen from Key Largo, Florida, V–1–53, NJ & ELS, (ELS), taken at light; the second example, Monroe Co., Florida, V–8–57, R. D. Alexander and ELS, (ELS), taken from beneath prostrate *Opuntia* sp. on Cape Sable. *G. fasciata* is somewhat divergent from the other forms occurring in eastern United States, leading the author to believe that perhaps it has been introduced into Florida, perhaps from Yucatan or Mexico proper. The type was from Buck Key, Florida.

Rhynchophorinae

Yuccaborus LeConte (Sipalini)

The late L. L. Buchanan expressed (in litt.) the opinion that in the genus *Yuccaborus* LeConte there is probably only a single species *frontalis* (LeConte) with a race *grossus* Casey; *lentiginosus* Casey being a smaller, more finely punctate form of the latter.

Recently, I have had the opportunity to study a large series of this genus. As a result of this study I feel that in the United States there are two species, *frontalis* (LeConte) and *grossus* Casey. They may be separated as follows:

1. Shining, reddish black with the punctation of the upper surface fine; elytral striae feebly impressed, strial punctures smaller and more widely separated, elytral intervals appearing flat; spermatheca as in figure 5; range California, (western and south western Mojave Desert and adjacent canyons and valleys) . . *frontalis* (LeConte)

1'. Dull, opaque black, punctures of upper surface coarser, deeper, more closely placed; elytral striae deeply impressed, strial punctures coarse, deep more or less rectangular, elytral intervals appearing more elevated; spermatheca as in figure 6; range southern Texas (Brownsville to El Paso), southern New Mexico, and southern Arizona . . . . . *grossus* Casey

The shining black coloration of *frontalis* is very noticeable and by this alone it can be separated readily from *grossus* in collections. *Y. lentiginosus* is nothing more than a form of *grossus*. *Y. grossus* represents the western terminus of a cline of size, *lentiginosus* the eastern end. The pale spotting mentioned by Casey can be found in individual examples throughout the cline. The size of *grossus* increases from the east to the west. Largest examples seen (18 mm) were from southern Arizona (Baboquivari Mts.). A single male example, apparently *grossus* was collected at La Milla, Sierra de Juarez, Baja California, VIII–2–58, ELS, (ELS). This is not surprising as many of the weevils from that area are closely related to those of the Santa Rita and Huachuca Mts. of Arizona.

Cossoninae

A single example of *Eucoptus depressus* Wollaston was collected on Big Pine Key, Florida, V–1–53, NJ & ELS, (ELS), from beneath a leaf sheath of Royal Palm. Only a single example was found; an intensive search of numerous other leaf sheathes was fruitless. *Eucoptus depressus* was described from the province of Rio de Janeiro, Brasil and was reported by Buchanan (1947: 50) from numerous localities in Cuba, as well as from Montserrat, and Nicaragua. This species is 1.2–2.4 mm long; dark reddish brown; the funicle 7-segmented; elytral striae well-defined

with small, round punctures. The male has a small tubercle on midline of first abdominal sternite, and a transversely arranged pair of depressions on the metasternum just behind the mesocoxae. The rostrum of the female is a little longer and more slender than in the male. Abdominal sternites of female unmodified.

There has been some doubt expressed about the validity of the determination of the *Dynatopechus aureopilosus* (Fairm.) of my note in 1957: 42. The type of this species has not been examined; however, examples determined as such by Sir G. A. K. Marshall, collected at Suva, Fiji, 1920, Pemberton Collector have been examined through the courtesy of J. Balfour-Browne, British Museum (N.H.). All examples so noted, which are still in (ELS), are certainly the same species as those specimens determined by Marshall. Several other species of *Dynatopechus* are frequently intercepted at ports of entry, particularly in seed beads composed mostly of Job's Tears, *Coix* sp., and various Leguminosae such as *Mucuna* spp. and *Acacia* spp.

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SOME NEGLECTED ASPECTS OF PLANT MICROFOSSIL RESEARCH

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The increased utilization of plant microfossils, especially by industry, has served to emphasize problems which have existed for many years. One of these is the difficult problem of classification and the urgent need of giving it serious attention. There is also an increasing disregard for the botanical affinities of microfossils. This is somewhat disturbing since we are dealing with the field of biology and with entities possessing botanical significance. There are numerous reasons for the existing ambiguity in plant microfossil classification, and continuance of many present practices may well result in a taxonomic maze that will serve to impede progress in pollen and spore research. A general tendency to ignore natural affinities of dispersed spores is evident with even a brief perusal of current literature, and the presence of a few arbitrary features common between entities is being increasingly used as a classification tool. Part of the cause is readily apparent since plant microfossils have proven to be useful operational tools with industrial applications, and there is a natural desire to put the entities to practical usage as quickly as feasible. Very often it is possible to make stratigraphic correlations with plant spores or pollen without regard to their natural affinities.

There are numerous classification systems, all probably useful to some degree, none completely satisfactory, and all contributing further to the entangled nomenclature of plant reproductive disseminules. Most of these studiously avoid any systematic treatment using demonstrated connections between fructifications and their spores. Several workers have given attention to the nomenclatural problems, and as Sen (1958) has noted, one solution is to study spores from identified fructifications and thus determine the limits of a spore species. This may appear to be an appallingly slow method, but it is one which can provide concrete corrobora-

tive evidence of the relationship of spore forms and determine whether similarities possess phyletic implications. Too frequently, paleobotanical investigators persist in ignoring phyletic evidences even when demonstrated links between spores and fructifications illustrate the conspecific nature of isolated specimens. Some of the Paleozoic small spores stand out as glaring examples of the failure by investigators to heed botanical relationships.

The spore genus *Planisporites* is an example, for in it are forms which have no suggestion of a natural genus, while there are also included in it by some authors spores attributal to a parent fructification. In *Planisporites* we have a genus that, as defined by Knox (1950), included circular and triangular spores without ornamentation or with walls granular to punctate. Potonié and Kremp (1954) in emending Knox's genus made note of her broad definition and the inclusion of species which appeared referable to other established genera. They designated *Planisporites granifer* (Ibrahim) Knox as the genotype and restricted the genus only to species possessing very small, closely spaced coni as ornamentation. In their emendation, however, they also included circular and triangular spores in the genus, and indeed their emended description appears superficial. It seems only to serve as an additional dumping ground for several entities once assignable to *Punctatisporites*. Admittedly *Punctatisporites* has long needed redefinition as there is no semblance of a natural genus in its present state. However, *Planisporites* as emended by Potonié and Kremp does not indicate a natural division in the light of our paleobotanical studies, for there are several examples of spores attributal to parent cones and assignable to *Planisporites* (sensu Knox). Chaloner (1953c), in a treatment of *Sigillaria* fructifications, isolated and described from *Sigillariostrobus rhombibracteatus* microspores assignable to *Planisporites* (sensu Knox). He also noted that the microspores of *Mazocarpon oedipternum*, a Sigillarian cone, were similar to the spores of *S. rhombibracteatus*. Felix (1954), in a study of *Lepidostrobus Gallowayi*, found the microspores most nearly assignable to *Planisporites*. The fact that this cone does possess Sigillarian characteristics further suggests *Planisporites* to be Sigillarian.

This is not to suggest that spores of the fructifications noted above afford conclusive evidence of Sigillarian affinity, but here are examples which may be included in *Planisporites* as defined by Knox (1950) but must be excluded by the emendation of Potonié and Kremp (1954). Thus we have spores definitely assignable to the arborescent lycopods but without a generic designation as *Planisporites* is presently emended. Nameless or named, such spores offer a step from the taxonomic morass of the form genus *Planisporites*, but as used by recent workers such as Potonié and Kremp (1955) and Bhardwaj (1957) we still have a genus whose organic connection with a parent plant is unknown. If *Planisporites* were to be retained, it would have seemed more logical for the emendation to have applied it to spores with established affinities rather than to ignore those spores from described fructifications.

The small spore *Lycospora* is one of the most characteristic of the Paleozoic coals, and in all probability more is known about it than any other spore. Its natural relationship is well established with the arborescent lycopods of the coal forests. Present from the upper Mississippian, it is abundant in most Pennyslvanian deposits to the middle Missourian, where it abruptly disappears. The genus as defined by Schopf, Wilson and Bentall (1944) included small spores 18 to 45 microns, possessing an equatorial ridge without a distinct flange; it was assignable to the cone genus *Lepidostrobus*, the fructification in turn being borne on *Lepidodendron*. Subsequent workers, particularly Kosanke (1950) and Potonié and Kremp (1955), have noted a membranous, continuous flange in species assignable to *Lycospora*. However, Hoffmeister, Staplin and Malloy (1955) have transferred *Lycospora minutus*, *L. pseudoannulata*, and *L. punctata* to the genus *Cirratriradites*. They have distinguished between the genera in that *Cirratriradites*

has the sutures extending to the edge of the spore body and usually continued as thickenings to the edge of the equatorial flange; in *Lycospora* thickened extensions of trilete rays are not developed on the narrow equatorial girdle. This deduction is based on the absence of extensions of the suture onto the girdle of the genotype, *L. micropapillatus*.

The importance given the length of the suture's extension by Hoffmeister, Staplin and Malloy hardly seems warranted in light of other worker's results. Kosanke (1950) noted the rays generally extending nearly to, or to the margin of the spore coat. This writer has noted in coals, especially where *Lycospora* comprises a high numerical percentage, that there is often no established pattern of ray extensions. Particularly in the Index Hill coal of Morgan County, Kentucky (unpublished study), a flanged *Lycospora* was observed in which the rays sometimes continued to the edge of the flange, other specimens did not have the ray extensions, and occasionally specimens were viewed in which both types of rays were present on the same spore.

The presence of the small equatorial flange is a systematic difficulty since early known species of *Lycospora* were not described as having a distinct flange development. The distinct, membranous flange of the rather large *Cirratriradites* was therefore sufficient to set the genera apart. However, conclusive evidence that the systematic position of flanged, small spores should also be with *Lycospora* has been shown by studies of Chaloner (1953b) and Felix (1954), where the specimens were demonstrated to be microspores of *Lepidostrobus*. The larger *Cirratriradites*, including the genotype, agrees with *C. annulatus* Kosanke and Brokaw in most respects. The studies of Chaloner (1954) and Hoskins and Abbott (1956) have conclusively shown it to be a microspore of *Selaginellites*.

However, despite good morphological evidence that these two spore genera are assignable to two distinct cone genera, can the student of paleobotany assume that the establishing of natural affinities is sufficient for determining genera? Probably not always, since studies of Andrews and Pannell (1942) and Felix (1954) have shown that the microspores of *Lepidocarpon* are most nearly assignable to *Lycospora* and spores with and without flanges are present in the cone genus. Thus we may feel justified in the assignment of one group of small spores, possessing a varied ray and flange development, to *Lycospora* and others to *Cirratriradites* because of the morphological nature of the parent fructification. Yet we are forced by necessity to assign the small spore of a third morphological parent entity (*Lepidocarpon*) to *Lycospora* due to an inability to differentiate between the microspores of *Lepidostrobus* and *Lepidocarpon*. That all are from different plants is evident when morphological features of the parent cones are compared, and the megaspores of each is known and differ decidedly from one another.

Chaloner (1958b) has recently added to the uncertainty of lycopodiaceous cone genera identifications by describing *Densosporites* as the microspore of *Selaginellites canonbiensis*. Since *Cirratriradites* appeared to be the only microspore attributable to *Selaginellites*, it is apparent that a broad interpretation of the cone genus has been made. Future investigations of the arborescent and herbaceous lycopods will undoubtedly result in new interpretations. Of primary importance however, is that this represents the first definite correlation of *Densosporites* with a parent cone. These spores have long been one of the most common Paleozoic small spores, and evidence of their relationship is a welcome contribution to paleobotany.

These examples do raise the question as to the reliability of the small spores as indicators of fossil species. A further suggestion of their lack of reliability is illustrated in *Lepidostrobus pulvinatus* (Felix, 1954) where a considerable variation was noted in spores from individual sporangia. The size range and features of the rays and equatorial development differed to the extent that the spores would certainly have been included in more than one species had they been recovered from sediments. Must one assume then that the microspores are of limited use, and

that the megaspores and other plant organs are most reliable in defining species and of more correlative value? In all probability such an assumption is unwarranted since so many of the small spores have already proven of value in both local and regional correlations, but it is evident that much is still unknown about the smaller spores. Further research may well demonstrate the poor characters of some spores, but study could equally well bring clarification and greater value for them to the paleobotanist.

Another interesting case is *Calamospora*, one of the most numerous of the Paleozoic spores, yet one of the least utilized. On the basis of morphological variations several species have been described, but little use has been made of these stratigraphically. The fact that the spores are not easily segregated into restricted generic groupings has impeded their utilization, yet much is known about them, enough that is as to suggest significant developments from a determined effort to study their affinities to parent plants. It is certainly one of the most broadly related genera on the basis of evidence of natural relationships, and it includes both megaspores and microspores. However, present division of the genus renders it quite likely that this inclusion in one morphologic niche has resulted in some heterosporous Calamarian species being recorded under two specific names.

Paleozoic literature abounds with references assigning the spore to a parent plant. Kosanke (1955) has reported *Calamospora* from the homosporous *Mazostachys pendulata*. From the heterosporous *Palaeostachya multifolia*, Anderson (1954) has described megaspores and microspores identified as *Calamospora*. Hoskins and Cross (1943) figured *Calamospora* as the spore of the homosporous *Bowmanites trisporangiatus*, and in their monographic treatment they assembled most of the published data on the spores of other *Bowmanites*. There are numerous publications dealing with the genus *Bowmanites*, a cone which Hoskins and Cross considered to be the fructification of Sphenophyllalean plants and with *Calamospora* as the spore. The question to be asked is whether these spores are sufficiently different morphologically to be distinguished when recovered from sediments? If so, they promise a valuable working tool in view of the known geological occurrence of many of the fructifications.

However, to add further to the uncertainties attending the identification of Calamarian forms is the problem of the proper relationships of these various cone genera containing similar spores. In addition to the previously noted cones, Arnold (1949) has described the cone *Discinites delectus* with megaspores and microspores of the *Calamospora* type. But doubt is cast on the dependability of the spores as generic indicators by *Bowmanites bifurcatus* of Andrews and Mamay (1951). In this *Bowmanites* the spores are reniform, monolete and assignable to *Laevigatosporites* rather than to *Calamospora*. A problem also exists as to the true nature of *Palaeostachya*. Anderson (1954) described *P. multifolia* as heterosporous, but Baxter (1955) has reported *P. andresii* with spores ranging from 270 to 320 microns in diameter and his description indicates that they are *Calamospora*. Delevoryas (1955) has reported *P. decacnema* with spores averaging 45 to 50 microns in diameter and referable to *Calamospora*. Thus the possibility exists that some species possess microspores only and others megaspores. Until further research establishes heterospory, homospory, or both in the genus, the spores can be considered of limited specific importance. Thus we have the spore *Calamospora*, often of considerable quantitative significance and of much morphologic variability, yet tantalizingly of questionable value until we have more knowledge of the true relationship of spores to parent fructifications.

That all problems relating to Sphenophyllalean taxonomy have not been conclusively resolved is further suggested by the association of the spore *Reticulatisporites* with apparent sphenopsid cones. Levittan and Barghoorn (1948) have

reported it as the spore of *Sphenostrobus Thompsonii*. Mamay (1954) has figured reticulate spores from *Lithostrobus iowensis*, a cone of Sphenophyllalean affinity.

These examples constitute only a small portion of the issues to be dealt with in plant microfossil classification. They are questions which appear to have solutions if properly studied from the standpoint of megafossils as well as microfossils and with the botanical aspect receiving consideration. Most importantly they reveal to the young researcher the immediate and plentiful problems available for investigation. The opportunities for research in plant microfossil work as related to megafossils is virtually unlimited. Our ignorance of the proper relationships between spores and fructifications for instance is not due to a scarcity of material. The fine coal ball horizons of the mid-continent have revealed many links in the paleobotanical picture, and their resources have scarcely been tapped. The equally promising coal ball localities of the Appalachian region still remain to yield their first publication. The splendid reservoir of research in Paleozoic compressions and impressions has received only the barest attention, and the publications of Chaloner (1952, 1953a, b, c, 1954, 1956, 1958a, b) serve to illustrate the vast untouched potential of museum and academic collections.

There is a readily discernible antipathy towards botanical methods in current plant microfossil studies. Such is frequently the case when a specific field of study becomes popularized and attains a "bandwagonlike" stature, for it is often easier for the non-botanist to ignore the fundamentals upon which paleobotany is based and turn the proven substantiations into usable tools. Admittedly this use of affirmed knowledge is one aim in spore-pollen investigations but not the sole goal. Such an attitude is not progress; it is stagnation, and it bids well to create only capable mechanics and not scientists. Such interpretive discrimination will turn taxonomy into a mere cataloging process if investigators persist in ignoring the significance of the many biocharacters afforded by study of megafossils and their associated microfossils.

There is a real need to remain cognizant of the fact that spore-pollen investigations are basically botanical. Especially is there a need for investigators to collaborate more in sharing results, for it seems that as a rule those who persist in operating amid an atmosphere of secrecy set poor examples and seldom contribute to paleobotanical progress. Cooperation among paleobotanists is essential in order that we may also obtain a general stratigraphic correlation of the megafossils to supplement our spore studies in the solution of stratigraphic and floristic problems of paleobotany.

Much of the responsibility for bringing order from the abundance of information we have on plant microfossils must be directed towards the establishments utilizing the fundamental data. The academic researchers have laid an admirable groundwork, often under difficult circumstances, but they did it slowly and intelligently, not in the pellmell probing for short cuts. Taxonomy studies progress slowly at best and are likely to be treated impatiently by those prone to speedy decisions or the "talent" for resolving every problem even if by a superficial evaluation of data. But thorough taxonomic treatment of fossil plant entities is necessary if real progress is to be realized. This writer does not assume the gross conceit that we can define ancient plants so perfectly as to designate them as "natural" genera or families. There will probably always be certain members of any taxonomic division whose affiliations will be less well understood, or whose definitive characters will be indistinct enough, so that the marginal outlines of the alliance will be established with some degree of unnatural arbitrariness. It is also noted that the author has made free use of the distinguishing of *natural* and *form* genera largely because of time honored precedent, not because he considers them to be good taxonomy.

SUMMARY

There is a need in plant microfossil research to give more attention to nomenclatural problems. Present classification systems often persist in ignoring phyletic relationships even when natural affinities of dispersed spores are evident. Many current taxonomic problems may have solutions if studied from the standpoint of megafossils as well as microfossils and with the botanical aspect considered.

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CORRELATION OF TILLS EXPOSED IN TOLEDO EDISON DAM CUT, OHIO

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INTRODUCTION

Two tills, separated by a cobble pavement and overlain by lacustrine and alluvial deposits, are exposed in the east bank of the Auglaize River three miles south of Defiance, just north of the Toledo Edison Dam. This section is of significance because these tills have mechanical compositions which match those of the two tills described on the north side of Lake Erie by Dreimanis (1957, and Dreimanis and Reavely, 1953) and two of the three tills mapped in northeastern Ohio by White (1952, 1953, and White and Shepps, 1952) and described by Shepps (1953). Because of its proximity to the dam, this exposure is referred to as the Toledo Edison Dam cut.

LOCATION

The Toledo Edison Dam cut is an exposure about a quarter of a mile long in the east bank of the Auglaize River, a quarter of a mile north of the relatively new Toledo Edison Dam and approximately three miles south of the town of Defiance. The site occurs just north of the mouth of Jackson Ditch, in the southwest quarter of section 3, T3N, R4E, Defiance Township, Defiance County (near the north edge of the Continental quadrangle).

STRATIGRAPHY

The stratigraphic sequence exposed in the Toledo Edison Dam cut, which is illustrated in figure 2, consists of the following units:

7. 0–5' Alluvium, leached reddish alluvial silt and gravel, present mainly in the southern part of the cut, with Lucas silt loam soil, sandy substratum phase, developed in it (described by Francis Baker, Ohio Division of Lands and Soil).
6. 3–5' Lake silts, leached, locally poorly laminated, thicker toward the north end of the cut, where some sandy material is present near base of unit.
5. 2–8' Till, clayey (sand-silt-clay ratio: 18–40–42), dark blue-gray, thicker toward the northern end of the cut.
4. 0–1' Sand and sandy gravel, present only in the northern part of the cut.
3. 0–1' Till, very sandy (sand-silt-clay ratio: 59–34–7), present only in the northern part of the cut where it is associated with the overlying sand (unit 4).
2. 6–10' Till, clayey (sand-silt-clay ratios: 20–43–37 at north end of cut; 22–43–35 and 19–45–36 at south end of cut), bluish-gray, somewhat thicker toward northern end of cut.

   Separated from underlying till by incomplete pavement of cobbles four to eight in. in diameter, composed dominantly of crystalline rocks (gneiss, diorite, basalt, also limestone), with striations oriented from S 53° W to S 62° W.
1. 8' Till, sandy (sand-silt-clay ratios: 54–38–8 at north end of cut; 52–41–7 and 51–39–10 at south end of cut several feet below contact and 39–43–18 only 18 in. below contact), unoxidized brownish-gray; containing several discontinuous horizons of cobble pavement, none of which appear to separate different tills, cobbles composed mostly of dolomite, with striations oriented from S 47° W to S 64° W.

SURFACE SOIL PROFILE

The soil developed at the top of this section is the Lucas silt loam, sandy substratum phase, and has been described by Mr. Francis Baker, of the Ohio Division of Lands and Soil (personal communication, 1957). His description, greatly abbreviated, is as follows:

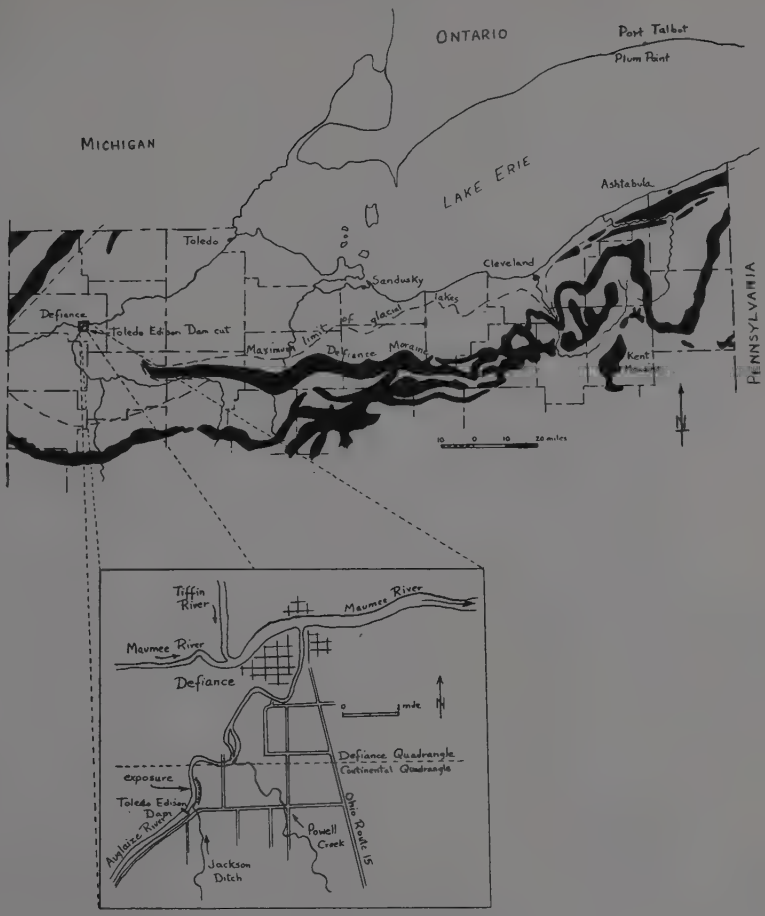

FIGURE 1. General location of Toledo Edison Dam cut.

Ap	0–6"	Dark brown silt loam with light yellowish-brown mottling (probably the result of ancient plowing), fine granular structure.
A_2	6–8½"	Light yellowish-brown silt loam with medium granular structure.
B_1	8½–14"	Brown fine silty clay loam, with medium subangular blocky structure.
B_{21}	14–22"	Brown silty clay peds (structural masses) coated with very thin continuous dark brown clay skins, strong angular blocky structure.
B_{22}	22–33"	Dark yellowish-brown peds, mottled with grayish-brown, of fine silty clay, coated with thin continuous grayish-brown clay skins, blocky structure.
B_3	33–39"	Dark brown peds, mottled with light brownish-gray, of silty clay, coated with thin continuous grayish-brown clay skins and dark brown manganese coatings, angular blocky structure.
D_1	39–44"	Finely mottled yellowish-brown and dark brown clay loam peds, coated with thin discontinuous grayish-brown clay skins, weak subangular blocky structure.
D_2	44–114"	Brown sandy clay loam with yellowish-brown mottling, massive.
D_3	114±"	Yellowish-brown calcareous silty clay till mottled with grayish-brown.

FIGURE 2. Diagrammatic cross section illustrating stratigraphy exposed in Toledo Edison Dam cut.

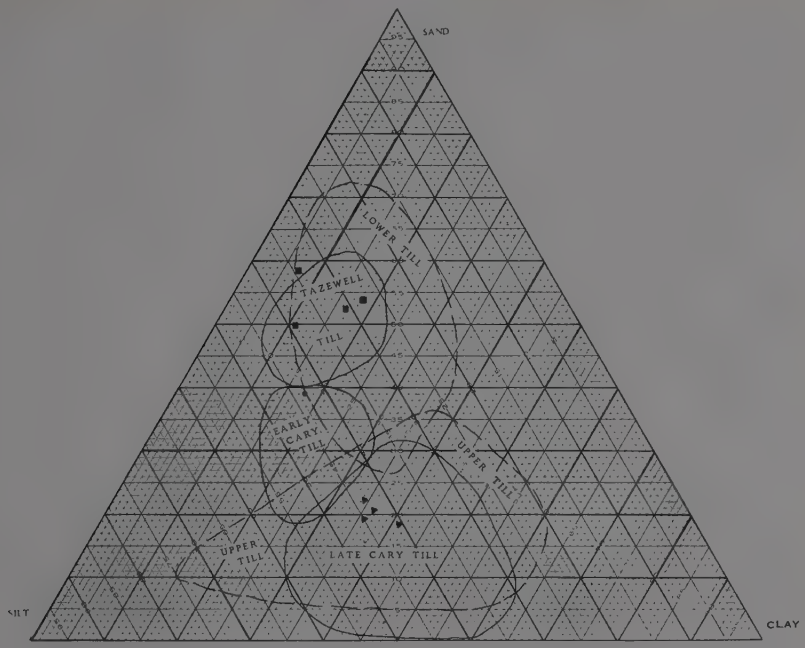

FIGURE 3. Triangular diagram showing results of mechanical analyses
from northeastern Ohio (*shown by solid lines*, taken from Shepps, 1953, p. 39, fig. 2),
from southern Ontario (*shown by dashed lines*, taken from Dreimanis and Reavely, 1953, p. 246, fig. 3), and
individual determinations from the Toledo Edison Dam cut (upper till *shown by triangular spots*; lower till *shown by square spots*).

COMPARISONS OF MECHANICAL ANALYSES AND CONCLUSIONS

In his report on the tills of northeastern Ohio, V. C. Shepps (1953) reported strikingly consistent differences in the mechanical compositions of the three tills shown by G. W. White (1952, 1953, 1957) to have characteristic and persistent stratigraphic and geographic distribution. In order of increasing age, these tills are called (1952, 1953) late Cary, early Cary, and Tazewell. The ranges in mechanical composition of these three tills, as determined by Shepps (1953, p. 43), are:

	% Sand	% Silt	% Clay
late Cary	4–31	29–58	29–63
early Cary	19–39	37–55	16–30
Tazewell	42–60	26–45	10–23

In spite of careful work (Campbell, 1955; Gregory, 1956), it has not previously been possible to trace these drifts west of Ashland County.

Dreimanis and Reavely (1953) reported two distinct tills, an upper clayey till and a lower more sandy till, along the north shore of Lake Erie. The general ranges in mechanical composition of these two tills are:

	% Sand	% Silt	% Clay
upper till	6–35	20–58	23–62
lower till	28–70	17–43	6–36

Dreimanis also noted (p. 243), ". . . several *boulder pavements* or sheetlike *accumulations of cobbles* were found either at the base of, or within the lower till," just as has been described in the Toledo Edison Dam cut.

On the triangular diagram (fig. 3) are outlined areas enclosing the characteristic compositions of each of the tills described by Shepps and by Dreimanis. The individual analyses of the tills exposed in the Toledo Edison Dam cut are shown by spots, triangular shaped for analyses of the upper till and square for analyses of the lower till.

It will be seen immediately that the mechanical compositions of Shepps' late Cary till and of Dreimanis' upper till are strikingly similar (as pointed out by Dreimanis and Reavely, 1953 p. 246) and that the analyses of the upper till at the Toledo Edison Dam cut fit squarely into the middle of this same area. The nature of Dreimanis' lower till matches, though less precisely, the characteristics of both the Tazewell and the early Cary tills of Shepps. Dreimanis is aware of this since he said (p. 246), "The lower till of the north shore of Lake Erie, however, corresponds to either the early Cary or the Tazewell tills of northeastern Ohio, if correlated on the basis of grain-size analysis." This would suggest that the time represented by White and Shepps' two lower tills might equal that of Dreimanis' lower till; two fluctuations of the ice front in northeastern Ohio may be contemporaneous with a single continuous advance north of Lake Erie. The lack of precise agreement between the plots of Dreimanis' lower till and White and Shepps' two lower tills is probably due to the fact that the upper corner of Dreimanis' triangular diagram is "sand and gravel," rather than just "sand" as is true on Shepps' diagram. (This lack of consistency is true for both the upper and lower tills, but only in the lower till is the coarse fraction great enough to introduce some discrepancy. The gravel fraction was also disregarded in the Toledo Edison Dam cut samples.)

The hypothesis that Dreimanis' lower till is contemporaneous with both the early Cary and Tazewell tills of White and Shepps is supported by the few mechanical analyses of the lower till at the Toledo Edison Dam exposure. Most of the samples of this lower till were taken three to six ft below the contact and plot within Shepps' Tazewell area of figure 3. One sample, however, has somewhat less sand than the others and plots within the margin of Shepps' early Cary area; this sample was taken only 18 in. below the contact and within the area of the discontinuous cobble pavements. This modification in mechanical composition may indicate a change in ice age conditions which, in northeastern Ohio, resulted in the deposition of two distinct tills.

Therefore, I believe that the upper till at the Toledo Edison Dam cut is the same as Dremanis' upper till and Shepps' late Cary till, and that the lower till at the Toledo Edison Dam cut is equivalent to Dremanis' lower till and generally to both the Tazewell and early Cary tills of Shepps. The fact that these tills occur in similar stratigraphic relationships and have such strikingly similar mechanical compositions suggests that the glacial history must have been about the same throughout the entire Lake Erie basin and surroundings during this late Wisconsin time.

AGE OF THE TILLS

Dreimanis has obtained radiocarbon dates which limit the ages of both his upper and lower tills (Dreimanis, 1957, 1958). Wood from near the base of the lower till is dated at 28,200 ± 1500 (L 185B), 27,500 ± 1200 (W 177) and 24,600 ± 1600 yr (L 217B). These dates are not significantly different from the date of 24,600 ± 800 yr (W 71) obtained on wood collected by White from lake deposits associated with the Wisconsin glacial advance in Cleveland, or from other Ohio dates like 23,000 ± 850 (Y 449) in Columbus, 21,400 ± 600 (W 88) in Newark, or 23,000 ± 800 yr (W 188) in Sidney. Other dates from farther south in Ohio show

that this ice advance reached its southern boundary near Chillicothe and Oxford about 18,000 yr ago and then began to retreat (Goldthwait 1958).

The next younger dates are for postglacial materials. Driftwood from lake deposits lying directly above the upper till in southern Ontario is dated at 12,660 ± 440 yr (S–25). Similar dates have been obtained from postglacial materials in Ohio: 13,600 ± 500 (W–33) in Cleveland, 12,920 ± 400 (W–430) south of Sandusky, and 12,800 ± 250 yr (Y–240) at Bellevue.

The older dates listed above are obtained from wood embedded in the base of the lower sandy till or, farther south in Ohio, in the base of the surface till; the younger dates come from nonglacial materials lying directly on the youngest till (Dreimanis, 1957; Goldthwait, 1958). Thus, these two age groups mark the beginning and end of a major Wisconsin glacial advance which included, near the end of the interval, a less extensive readvance associated with a more clayey till.

As defined in Illinois, the classic Wisconsin is represented by radiocarbon dates varying from 25,100 ± 800 (W–69) at Farmdale, Illinois, to 12,200 ± 350 yr (W–161) at Dyer, Indiana (Horberg 1955). Thus, based on radiocarbon dates, all the tills discussed in this paper, including the two tills exposed in the Toledo Edison Dam cut, appear to represent the entire interval of classic Wisconsin time.

SUMMARY

An exposure in the east bank of the Auglaize River just downstream from the Toledo Edison Dam, three miles south of Defiance, Ohio, reveals two tills, separated by a cobble pavement and overlain by lacustrine and alluvial deposits. The upper till is clay-rich, with a mechanical analysis that fits within the ranges of both the late Cary till of northeastern Ohio (Shepps, 1953) and the upper till of southern Ontario (Dreimanis and Reavely, 1953). The lower till is much sandier, with a mechanical composition that fits within the ranges of the sandier Tazewell till of northern Ohio and the lower till of southern Ontario.

One sample of this lower till, taken not far beneath the contact with the upper till, has a mechanical composition more like that of the early Cary till of northeastern Ohio suggesting that, in this area, there was a transition, near the end of the time during which the lower till was deposited, to conditions leading to the deposition of a till more like that of the early Cary.

Because the mechanical analyses of the tills and their relative stratigraphic positions are almost the same in northeastern Ohio, southern Ontario, and in the Toledo Edison Dam cut, it is inferred that the glacial history of the three areas must have been almost the same, thus providing a basis of correlation between these areas.

Radiocarbon determinations give a date of 24–27,000 yr ago for the advance of the glacier which deposited the lower sandy till. By about 12,000 yr ago, both the sandy and clayey tills had been deposited and the ice had made its final retreat from the area. On the basis of comparison with radiocarbon dates in Illinois (Horberg, 1955), this ice advance and retreat appear to have occupied the entire classic Wisconsin interval.

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FREQUENCY CALCULATIONS FROM SEVERAL DIFFERENT FOREST ECOLOGICAL SAMPLING METHODS[1]

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In forest ecology, the concept of the phytosociological relationship species frequency is associated most commonly with the quadrat and has been defined essentially as the number of quadrats containing the species divided by the total number of quadrats (Curtis and McIntosh, 1950). Greig-Smith (1957) defines the frequency of a species, determined by a particular size sample, as the chance of finding the species within any one trial. Frequency has also been similarly defined as the probability of encountering the species in a specific subsample (Shiue and Beazley, 1957). The numerical value of species frequency will vary with the particular definition of subsample, even for the same stand. The dependency of species frequency upon the definition of subsample has led to the consideration that species frequency may not be characteristic of the population sampled, but rather of the sampling method itself (Kylin, 1926).

The purpose of this study is to show that species frequencies, as estimated from several different sampling methods with different definitions of subsample, can be compared if for all sampling methods, species frequency, species density, and relative species density are reduced to common terms.

For the purposes of this study, the terms species frequency, species density, and relative species density are defined as follows: Species frequency is the probability of encountering the species of interest in a specific subsample (Shiue and Beazley, 1957); Species density is the number of stems of the species of interest per unit area (a variation of species density is subsample species density which is defined as the number of stems of the species of interest per subsample); Relative species density is the probability of encountering the species of interest sampling the stems one at a time. Relative species density therefore equals subsample species density when the subsample is one stem. Actual sampling measurements then are used to estimate these population parameters. In order to distinguish

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the density of a single species from the density of the stand the term species density is used and to keep the usage uniform the adjective species has to be used with frequency. Subsample is used in its most general sense and may relate to any sampling method.

METHODS AND DISCUSSION

A tract of Maple-Basswood forest, with a White Pine overstory, in the Itasca State Forest, Minnesota, 40 x 120 meters was mapped and sampled. The mapping was accomplished by means of a plane table and all tree species individuals with stems one inch or more DBH were identified and located on the map. Since the map was a nearly exact scale duplication of the forest stand, all sampling was performed using the map. Sampling was accomplished by establishing a coordinate system on the map and selecting random pairs of coordinates to position subsamples by means of a table of random numbers. The coordinate system used consisted of a 40 point ordinate and a 120 point abcissa, with the points 1 meter apart making possible the selection of 4800 total non-repeated subsamples. However sampling was carried out with replacement.

TABLE 1

Subsample density, (10 x 10 meter quadrat), and relative density for the quadrat, plotless variable radius, and the point quarter sampling methods

	Subsample density[2] (Quadrat)			Relative species density		
	Q[3]	PVR[4]	PQ[5]	Q	PVR	PQ
Acer saccharum Marsh.[1]	2.000	1.930	3.986	0.329	0.128	0.338
Tilia americana L.	1.225	1.088	1.226	0.202	0.088	0.106
Populus tremuloides Michx.	0.850	0.562	1.515	0.140	0.163	0.131
Quercus rubra L.	0.750	0.204	1.515	0.123	0.059	0.131
Pinus strobus L.	0.575	0.304	1.948	0.095	0.374	0.169
Quercus macrocarpa Michx.	0.225	0.350	0.288	0.037	0.009	0.025
Acer rubrum L.	0.175	0.152	0.577	0.029	0.009	0.050
Betula papyrifera Marsh.	0.100	0.146	0.216	0.018	0.038	0.019
Populus grandidentata Michx.	0.100	0.039	0.288	0.018	0.007	0.025
Ostrya virginiana (Mill.) K. Koch	0.050	0.434	0.072	0.008	0.021	0.006
Ulmus americana L.	0.025	0.007	xxxxx*	0.004	0.002	xxxxx
Pinus resinosa Ait.	xxxxx	0.030	xxxxx	xxxxx	0.021	xxxxx

[1]Nomenclature after Fernald (1950).
[2]Analysis of variance for both density and relative density indicate no significant differences among the methods at either the 0.05 or 0.01 levels of significance.
[3]Quadrat Method
[4]Plotless Variable Radius Method
[5]Point Quarter Method
*Did not occur in the sample

The methods compared in this study are the quadrat (10 m x 10 m), the point-centered-quarter method (Cottam and Curtis, 1956) and (Cottam et al., 1953) and the plotless-variable-radius method (Bitterlich, 1947) and (Grosenbaugh, 1952). The samples consist of 40 quadrats, 40 point-centered-quarter 4-tree subsamples, and 25 plotless-variable-radius points. The number of subsamples in each case are consistent with common usage. The sampling for any one method was completely independent of all other methods.

Since the primary concern of this paper is with the comparison of species frequency estimates, much of the information that would be normally presented in a full scale comparison of methods is omitted.

In table 1 are given estimated species densities for all species in all sampling methods. Inasmuch as quadrats are beyond doubt the most frequently used

sampling devices, all values are reduced to estimated quadrat species density; i. e., the density for each species for each method is given on a stems-of-the-species per 100 sq m basis.

The quadrat method yielded estimated quadrat species density directly. The plotless-variable-radius method estimated species density in stems per acre which was then converted to stems per 100 sq m. The point-centered-quarter-area calculations are based on the approximate spacing of trees in squares in which the average of the four measurements is considered to be $\frac{1}{2}$ the diagonal of the square. The area occupied by the 40 sets of 4 trees was then calculated and the appropriate transformation was made to trees per 100 sq m.

TABLE 2

Estimated species frequency and frequency derived from subsample (quadrat) species density, for all species and methods

	Estimated frequency			Density derived frequency[1]		
	Q	PVR	PQ	Q	PVR	PQ
Acer saccharum Marsh.	0.850	0.920	0.850	1.000	1.000	1.000
Tilia americana L.	0.625	0.720	0.300	1.000	1.000	1.000
Populus tremuloides Michx.	0.450	0.960	0.350	0.350	0.562	1.000
Quercus rubra L.	0.525	0.760	0.425	0.750	0.204	1.000
Pinus strobus L.	0.350	1.000	0.525	0.575	0.304	1.000
Quercus macrocarpa Michx.	0.175	0.120	0.100	0.225	0.350	0.288
Acer rubrum L.	0.175	0.120	0.200	0.175	0.152	0.577
Betula papyrifera Marsh.	0.100	0.440	0.100	0.100	0.146	0.216
Populus grandidentata Michx.	0.100	0.040	0.100	0.100	0.039	0.288
Ostrya virginiana (Mill.) K. Koch	0.050	0.200	0.025	0.050	0.434	0.072
Ulmus americana L.	0.025	0.040	xxxxx	0.025	0.007	xxxxx
Pinus resinosa Ait.	xxxxx	0.360	xxxxx	xxxxx	0.030	xxxxx

[1]Analysis of variance for density derived frequencies indicate that there are no significant differences among the methods at either the 0.05 or 0.01 level of significance.

It is possible to estimate species frequency directly by dividing the number of subsamples containing the species by the total number of subsamples. Table 2 contains estimated species frequencies based on this procedure.

The sample area for quadrats is 100 sq m with an average of 6.08 stems per subsample. The average subsample area for the plotless-variable-radius method is 500.37 sq m, containing 16.88 trees per subsample and for the point-centered-quarter method the average subsample size is 34.67 sq m with 4 trees per subsample. These estimates of species frequencies are not directly comparable for they are based on systems using different area measures.

Because direct comparisons of the estimated species frequencies among methods are out of the question other aspects of species frequency must be examined.

As stated previously, species frequency can be defined as the probability of encountering a given species in a specific subsample. Thus species frequency can be estimated from species density and can be illustrated with an example.

If *Pinus strobus* has a subsample (quadrat) species density of 0.575 (see table 1), 0.575 stems of *Pinus strobus* occur on the average in each subsample (10 x 10 m quadrat), one stem would occur on the average in about every 2 quadrats, or *Pinus strobus* stems would occur on the average in about $\frac{1}{2}$ the quadrats. If this is true, then *Pinus strobus* would have an estimated species frequency of about 0.5.

If *Acer saccharum* were chosen with its subsample (quadrat) species density of 2.000 (table 1), its estimated species frequency would be approximately 1.0, for with two stems per quadrat, the chances are good that almost every subsample would have at least one *Acer saccharum* stem.

TABLE 3

Estimated species frequency derived with the use of the Poisson Series and estimated species frequency derived with the use of the Binomial Series for all species and all methods

	Poisson frequency[1]			Binomial frequency		
	Q	PVR	PQ	Q	PVR	PQ
Acer saccharum Marsh.	0.865	0.855	0.976	0.797	0.422	0.808
Tilia americana L.	0.706	0.663	0.701	0.595	0.308	0.362
Populus tremuloides Michx.	0.572	0.430	0.780	0.530	0.510	0.430
Quercus rubra L.	0.528	0.141	0.780	0.409	0.216	0.430
Pinus strobus L.	0.437	0.262	0.854	0.329	0.847	0.524
Quercus macrocarpa Michx.	0.168	0.295	0.250	0.140	0.036	0.186
Acer rubrum L.	0.161	0.141	0.438	0.111	0.036	0.186
Betula papyrifera Marsh.	0.095	0.136	0.194	0.071	0.144	0.074
Populus grandidentata Michx.	0.095	0.038	0.250	0.070	0.028	0.096
Ostrya virginiana (Mill.) K. Koch	0.049	0.239	0.070	0.032	0.083	0.023
Ulmus americana L.	0.024	0.007	xxxxx	0.016	0.008	xxxxx
Pinus resinosa Ait.	xxxxx	0.030	xxxxx	xxxxx	0.021	xxxxx

[1]Analysis of variance for both groups indicate no significant differences among the methods at either the 0.05 or 0.01 level of significance.

If the stems are distributed in a random or uniform manner, estimated subsample density should be a good estimate of species frequency. If the stems are clumped the species frequency estimates will be high.

The tendency for species to be randomly distributed and to be clumped may well exist in the same stand simultaneously. Whitford (1949) has shown that the tendency toward random or clumped distributions is related to the age of the stand.

Table 2 contains estimates of species frequencies computed from subsample (quadrat) species density. When compared to estimated quadrat frequency, the estimates of species frequencies for quadrats derived from estimates of species density appear to be too high. Most of the plentiful species have estimates of species frequencies of 1.000 and this is borne out even with the other methods. However, the transformation from estimated species density to estimated species frequency yielded values that were all biased in the same direction. Since this method of calculating species frequency depends entirely upon the random or uniform distribution of the stems in areal extent, there is a strong presumption that this is not so.

If an hypothesis involving the randomness or nonrandomness of the areal distribution of the species underlies the sampling method, other relationships among species frequency, species density and relative species density may be derived from the hypothesis.

The hypothesis that the species were distributed in the population of quadrat subsamples according to the Poisson series, and the hypothesis that the species were distributed in the population of point-centered-quarter subsamples according to the binomial series were tested. From the results of a Chi-square test for goodness of fit, it could be concluded that there was not sufficient evidence to reject the hypothesis for the major species for the Poisson series, nor was the evidence sufficient to reject the hypothesis for any of the species for the binomial.

For the Poisson distribution the expectation of the occurrence of subsamples containing 0, 1, 2, 3, . . . of the species is given by the sequence $\frac{n}{e^d}, \frac{nd}{e^d}, \frac{nd}{2e^d}, \frac{nd}{6e^d}$, . . ., where n equals the number of subsamples, e is the base of the natural logarithms, and d is the mean occurrence of the species in the subsamples (Snedecor, 1946). The factor d is subsample or quadrat species density.

The first term of the series will yield the expected number of subsamples in the total sample that do not contain the species. The next term will yield the expected number containing one of the species, the next, the number containing two, etc.

If the expected number of subsamples containing none of the species can be derived from the Poisson series, then by subtraction the expected number with the species can be determined. This information, together with the total number of subsamples, is all that is necessary to estimate species frequency.

Using estimated quadrat densities for all methods (table 1), the expected species frequencies for all species for all methods were computed using the Poisson series. This was done by substituting the estimated quadrat densities for d in the Poisson series.

Table 3 contains estimates of species frequencies for all species, for all methods computed from estimated quadrat density and using the Poisson series. With the Poisson distribution it is a fact that some degree of clumpedness will occur. This is in keeping with the expectation that with the Poisson most or many of the subsamples will not contain the species of interest and that some of the subsamples will have 1, 2, 3, 4, or more of the species of interest each. The general effect is to lower the species frequencies of the abundant species while leaving virtually unchanged the species frequencies of the less abundant ones. F-ratios indicate no significant differences for the three methods, indicating that each method estimated the quantity species density within bounds such that the subsequent transformations yield differences that were not significant.

For the point-centered-quarter method the binomial distribution was applied in the following way. Assuming relative species density to be the probability of encountering the species in the stand in subsamples of 1, a binomial expression was formulated in terms of relative density, and is: $(p+q)^k=1$, where p is the probability of encountering the species in the stand (relative species density), where q is the probability of not encountering the species, and where k is the number of trees in the subsample. In the point-centered-quarter method, $k=4$.

When this binomial expression is expanded and its terms multiplied by the total number of subsamples, (40 for the point-centered-quarter method), the expected numbers of subsamples containing k . . . 3, 2, 1, and 0 of the individual species are obtained. The expansion for the point-centered-quarter is: $np^4+n4p^3q+n6p^2q^2+n4pq^3+nq^4$, where n equals the total number of subsamples.

This led to another series of calculations of expected species frequencies based on the binomial series, where nq^4, the expected number of subsamples without the species, was evaluated for each species. With this information estimates of species frequency of each species was calculated using the relative densities of table 1 for all methods.

Table 3 contains estimates of species frequencies for all species, for all methods computed from relative species densities and using the binomial series. Much the same has occurred with estimated species frequencies calculated from the binomial mathematics as had occurred with the Poisson. Again the expectation with the binomial is that a definite proportion of the subsamples will have none of the species of interest, while some others will have 1, 2, 3, or more depending upon the power of the binomial. F-ratios indicate no significant differences among the methods, again indicating that the method of estimating relative species density was such that nonsignificant differences of estimated species frequency resulted. The results from both the Poisson and the binomial would seem to indicate that in order to make good estimates of species frequencies, good estimates of species density must first be made since species frequencies can be thought of as a function of species density as limited by subsample size. Since nonsignificant differences were found within each method tested, it is apparent that the calculation and com-

parison of estimated species frequency also depends to a great extent upon the assumptions underlying the sampling technique.

CONCLUSIONS

It is concluded from the foregoing analysis that as far as the stand under study is concerned, estimated species frequency from several sampling methods including area sampling methods and plotless methods may be compared. The only requisite of the comparison is that the terms of species frequency be identical and this may be accomplished by transforming them into common terms.

Species frequency derived from estimated species density and based upon the assumption of the random distribution of trees areally yields estimated species frequencies values that are biased in the direction of being high. However, statistically the differences between estimates from all methods tested were not significant indicating that all estimates are biased in the same direction.

Estimated species frequencies calculated from Poisson and binomial distributions were also statistically nonsignificant but the estimated species frequencies for the most abundant species were somewhat reduced.

SUMMARY

By transforming the data for estimated species frequency from each of three different sampling methods into common terms, a comparison of estimated species frequencies was made. Analysis of variance conducted on each method of computing estimated species frequency indicated no significant differences among the methods.

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THE ECOLOGY OF WATER AREAS ASSOCIATED WITH COAL STRIP-MINED LANDS IN OHIO[1]

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INTRODUCTION

With the advent of the open-pit method of coal mining in Ohio in 1914, commonly referred to as strip mining, a new ecological habitat developed in the state. For a period of 35 years, subsequent to that date, the majority of the spoil banks created were left ungraded. In the ravines between the spoil banks, in the final cuts and in valleys of old fields where haul roads were established, small lakes, ponds, pools and marsh habitats developed. In ungraded strip lands a great number of aquatic habitats now exist in various stages of ecological succession. Some are 45 years of age. Relatively small excavating equipment, available prior to World War II, limited the stripping to areas of shallow overburden. These early operations ranged over widely dispersed coal fields in the southeastern counties of Ohio. The result was the development of aquatic habitats in a variety of overburden conditions. Thus, the physico-chemical aspects as well as the biota of the aquatic habitats are varied. Use of larger and more powerful machinery, in recent years, has resulted in larger continuous blocks of strip-mined land including a greater number of water impoundments having essentially similar watersheds.

Some isolated reclamation work on strip land areas was initiated in 1923 in Ohio, but large scale planting and seeding did not begin until 1940. Research pertaining to forest reclamation potentialities of the strip lands was started in 1937 by personnel of the Central States Forest Experiment Station of the U. S. Forest Service in southern Ohio (Chapman, 1944). Studies pertaining to wildlife utilization of such reclaimed areas were conducted by Yeager (1941) in Illinois. Wildlife population and utilization studies on reclaimed Ohio coal strip lands were conducted by Riley in 1947, 1952, and 1954. The ecology and management of strip mine aquatic habitats were also studied, especially the flora and fauna of such areas and the effect of the various overburden materials on the acidity of the water. Additional information concerning the ecology of such water impoundments has resulted from studies in Iowa (Ruhr, 1952), in Illinois (Bell, 1956; Arata, 1957; Lewis and Peters, 1954; Maupan, Wells, and Leist, 1954), and in Missouri (Heaton, 1951; Parsons, 1956).

OBJECTIVES

The data presented in this paper are part of an extensive study conducted during the period from August, 1946 to October, 1951. Data from additional research conducted during the period from June, 1952 to October, 1957, are also included. Aquatic habitats were studied in 15 counties of Ohio located within each of the several spoil districts (fig. 1). Several strip mine ponds were observed in Indiana and Illinois, but data on these are not included in this paper.

The objectives of the study were: (1) to identify and determine ecological relations of plants and animals inhabiting the water and its environs, (2) to determine which materials of the overburden were important contributors to the

[1]The majority of data are from research conducted by the author for the doctoral dissertation in the Graduate School of The Ohio State University under the direction of Dr. Charles A. Dambach, then Associate Professor, Dept. of Zoology and Entomology. During the study the author held a Wildlife Research Fellowship provided by the Ohio Cooperative Wildlife Research Unit. Additional financial aid was furnished by the Ohio Reclamation Association through The Ohio State University Development Fund.

TABLE 1
Fertility of Lower Kittanning spoil from Wayne Twp., Tuscarawas County, Ohio

Sample site	pH	Active Calcium	Available Phosphorous	Available Potassium
South slope	5.3	L*	L	L
South slope	7.0	L	L	L
North slope	7.3	H	M	H
North slope	4.8	M	M	L
North slope	4.5	L	L	L
Ravine	7.2	H	M	M
Ravine	7.5	M	M	L
Ridge	4.0	L	L	L
Ridge	4.3	L	L	L
Ridge	4.9	L	L	L
Ridge	3.5	L	L	L
Ridge	3.9	L	L	L
Ridge	4.0	L	L	L
Lake bottom	5.7	L	L	L
Lake bottom	5.9	L	M	L

*(L)—Low (H)—High (M) medium.

formation of acid present in many strip ponds, and (3) to determine practical methods of managing the watershed and the pond.

EXTENT OF COAL STRIP MINING IN OHIO

Strip mining of coal occurs in 27 counties, chiefly in unglaciated southeastern Ohio (fig. 1). During the year 1956, this method of mining accounted for approximately 24,606,104 tons out of the total of 39,758,986 tons produced in Ohio, or approximately 61 percent of all coal mined in the state. Of the 27 counties in which strip mining occurs, three contiguous counties, Belmont, Jefferson, and Harrison, produced 44 percent of all coal strip-mined (Ohio Dept. of Industrial Relations, 1956).

Strip mining operations, according to the bulletin cited above, had affected 82,115 acres of land from January 1, 1948 to January 1, 1957. This acreage has been or is to be graded and reclaimed as required by the *Coal Strip Mine Land Reclamation Act*, enacted by the 98th Ohio General Assembly, 1949–1950. Prior to January 1, 1948, an estimated 42,000 acres had been affected but left largely ungraded (Ohio Dept. of Industrial Relations, 1955). Thus, in January, 1957, Ohio had approximately 124,115 acres of coal strip lands interspersed with numerous aquatic habitats.

Although these areas are quite scattered throughout southeastern Ohio, rather large local concentrations exist. For example, in January, 1950, approximately 42 percent of the strip lands were located in Jefferson and Harrison counties (Riley, 1957). Other rather large units of coal strip lands were located in Tuscarawas County—4,452 acres, Columbiana County—4,049 acres, and Perry County—3,770 acres.

STRIP MINING METHODS AND POND FORMATION

The open-pit method of mining coal is done with power shovels, draglines, and tractor-drawn scoops, each having different effects upon the deposition of the overburden forming the watershed, the future physico-chemical conditions of the water and the physical characteristics of the pond. The majority of the stripping is done with power shovels and draglines. In shovel stripping, the equipment rests on the coal seam, and the excavating bucket is moved upward

from the exposed coal to the top of the overburden material. The mixed material is then placed in a spoil bank which parallels the exposed cut. Thus, the toxic materials near the coal are mixed with the nontoxic materials near the surface. There is thus less chance of having the acid material deposited in patches.

During dragline stripping, the equipment rests at a higher elevation, and the overburden is removed in layers resulting in the lower, more acid materials being removed last and being placed on top of the spoil bank. With methods used prior to 1948, these patches remained in rather small areas, but under present grading operations, this material is now spread over much larger areas. In some instances operators may partially bury the more toxic materials. Thus, of these two methods, shovel operations are usually superior to those of draglines since the latter places large masses of acid material near or on the surface of the pond watershed. Oxidation of toxic material in the presence of water releases sulfuric acid (H_2SO_4) which accumulates in impoundments. Prior to 1948, rather small lakes and ponds formed between the spoil banks, while long, narrow ponds formed in the final cut. When larger equipment was used in areas of low overburden, a rather broad, oval-shaped impoundment remained.

During tractor and scoop operations, the top strata of the overburden are removed from rather large areas and this nontoxic material is placed on the bottom of the spoil pile, whereas the very acid material from layers directly above the coal seam are placed upon the surface of the spoil. Here grading can do little to cover or bury the acidic spoil. The lakes and ponds formed as a result of this type of operation usually are final cut lakes or oval inter-bank lakes, the latter being similar to many farm ponds. Still another type of pond is formed in valleys across which haul roads have been established. Much of the watershed for this type of pond usually consists of strip lands.

Following the removal of the coal from the pit area, either dams are constructed or sloughing of the highwall tends to cut off drainage from the area, thus creating an impoundment. Encouragement has been given to the operators to impound water where ever possible by recent amendments to the *Coal Strip Mine Land Reclamation Act* by the 101st Ohio General Assembly. The water areas created usually ranged from a fraction of an acre up to 13 acres with one extreme of 100 acres. Watersheds ranged from one to 30 acres with vegetative cover on the watershed ranging from 25 to 100 percent. Vegetation consisted largely of a mixture of trees, shrubs, and herbs. Some exceptions were found, however, in which either trees or grasses and legumes were dominant. Most of the lakes were less than 25 ft deep, with one mine water supply lake having a depth of 40 ft. In final cut lakes the vertical highwall and the spoil bank are soon modified by erosion and sloughing. In oval-shaped lakes, where the overburden was shallow, the sides were gently sloping and a rather dense cattail community developed.

The water holding capacity of the lake basin depends largely upon the disintegration of the clays and shales present. Finely disintegrated material aids in sealing the porous structure of the spoil bank. The most desirable impoundment sites are those consisting of clay, such as that found in the bottom of the final cut. In the ravines between the spoil banks, the spoil structure is very porous, a condition which decreases greatly during the first few months after stripping due to the settling of the spoil, the disintegration of clays and shales and the attendant erosion of these particles from the adjacent slopes. Although basins are developed in these areas, they do not retain water as readily as those in final cuts. They are, however, more productive of plant and animal life, especially during the first few years, due to rapid erosion and the leaching of various chemical elements from the slope.

GEOLOGY OF THE STRIP MINING AREA OF OHIO

Coal stripping operations occur largely within the Pennsylvanian System; some stripping occurs in a narrow belt of the Permian System along the upper

reaches of the Ohio River. The latter system is in parts of Belmont, Monroe, Washington, and Meigs Counties. The Pennsylvanian System, covering an estimated 12,340 sq miles (Stout, 1944), consists of some 50 coal seams interlain with thin bedded to massive sandstone, clays, iron ore bands, limonitic godes, shales (fossiliferous, calcareous, acid and carbonaceous in character), and thin to relatively thick beds of limestone. Along the north and west edge of the strip mine region small amounts of glacial till are also found.

The geologic strata overlying the various coal seams are referred to as overburden. Upon removal, this overburden is deposited in linear piles called spoil. Due to physical and chemical differences in the geologic strata, the spoil material pH, texture, structure, rate of weathering and overall chemical and plant growth factors exhibit a considerable range of variation. As a result of these differences and their effect on reclamation practices and management, including both land and water areas, the strip mining region of southeastern Ohio has been divided into eight districts (Limstrom and Merz, 1949) (fig. 1).

Nine seams of major importance are strip-mined in the eight districts. There are many instances were overburden materials, similar in their characteristics, will be found occurring in more than one specific district. On the other hand,

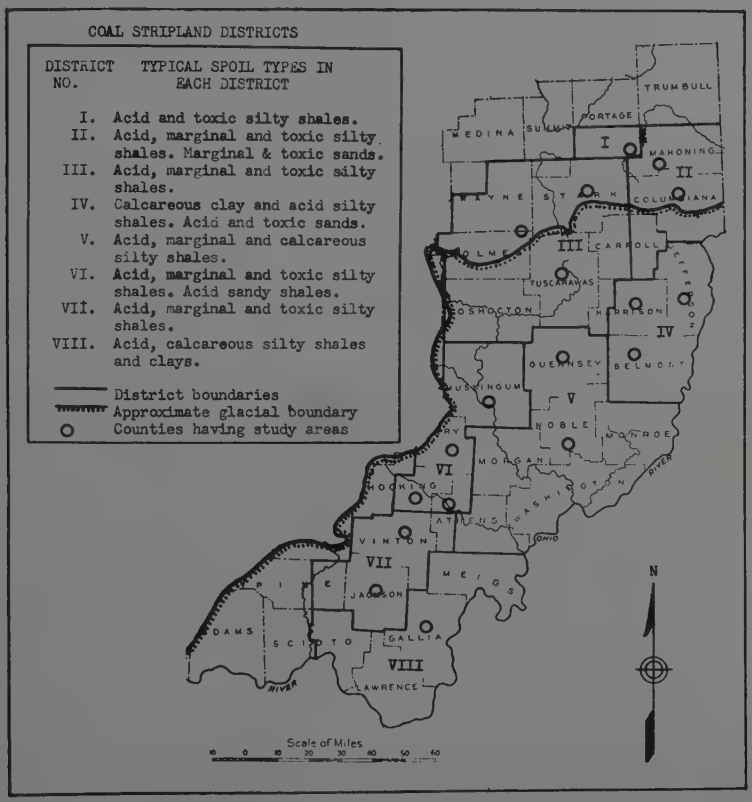

FIGURE 1. Ohio coal strip mining counties.

TABLE 2 *Effect of Lower Kittanning overburden materials on the pH of distilled water*

Date of pH test	Jan. 11	(1950) 18	25	Feb. 1	8	15	22	Mar. 1	8	15	22	29	Apr. 5	12	19	26	May 3	10	17	24	31	June 7	14	July 31	Aug. 7	14	21	28
Overburden Material*																												
FeS_2	3.4	3.2	3.1	3 0	3 0	2 6	2.7	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2 4	2.4	2.4	2.4	2.3	2.3	2 4	2.4	2.4	2.2	2.4	2.4	2.4	2.4
FeS_2+O_2	3.2	3.0	3.0	2.9	2 8	2.4	2.4	2.4	2.4	2.4	2 4	2.4	2.4	2.4	2 4	2.4	2.4	2.4	2.3	2.3	2.4	2.4	2 4	2.6	2.6	2.5	2.6	2.5
Cal. Shale	7.4	7.5	7.6	7.7	7.7	7.8	7.7	7.7	7.6	7.7	7 7	7.5	7.5	7.6	7 7	7.7	7.9	7.9	7.9	7.9	7 7	7.7	7.7	7.9	7.9	7.9	7.9	7.9
Cal. Shale+O_2	7.4	7.7	7.9	7.7	7 8	8 0	7.8	7.9	7.8	8.0	7 9	7.8	7.9	7.8	7.9	7.9	8.0	8.0	7.9	7.9	7 8	7.7	7 8	7.7	7.7	7.7	7.8	7.8
# 5 Coal	6.0	5.8	5.1	5.1	5 1	5.3	5.1	5.1	6.2	6.8	7 0	6.8	5.0	5.2	6 4	6.8	6.8	6.8	6.2	6.2	5 5	5.6	5 6	4.9	5.0	5.0	5.0	5.0
# 5 Coal+O_2	5.8	5.8	5.1	5.1	5 1	5.4	5.3	5.1	6.1	6.8	7.0	7.0	7.0	6.9	6 8	6.9	6.8	6.8	6.1	6.1	4 8	4.8	4.8	4.8	4.9	4.9	4.9	4.8
Carb. Shale	5.9	6.2	6.0	6.1	6.2	6.3	7.6	7.9	7.6	7.6	7.6	7.6	7.5	7.4	7.4	7.3	7.3	7.3	7.0	7.0	6.9	6.8	6.9	6.9	6.9	6.9	6.8	6.9
Carb. Shale+O_2	6.3	6.8	6.4	6.3	6.1	6.1	7.3	7.6	7.4	7.4	7 2	6.8	6.9	6.7	6.6	7.0	7.0	7.0	6.9	6.9	6.9	6.7	6 8	6.8	6.7	6.8	6.7	6.8
Blue Shale	7.2	7.5	7.7	7.7	7.7	7.8	7.7	7.7	7.7	7.9	7.7	7.6	7.5	7.5	7.6	7.6	7.7	7.7	7.7	7.7	7 6	7.6	7.6	7.7	7.7	7.7	7.8	7.8
Blue Shale+O_2	7.6	7.8	7.9	7.7	7.8	7.9	7.8	7.8	7.7	7.9	7 8	7.7	7.7	7.6	7.6	7.6	7.7	7.7	7.7	7.7	7 7	7.7	7 7	7.6	7.6	7.6	7.7	7.7
$FeCO_3$ 1949	7.6	7.4	7.7	7.7	7.8	7.7	7.7	7.8	7.7	7.7	7 7	7.6	7.6	7.6	7 8	7.7	7.7	7.7	7.9	7.9	7 7	7.7	7 7	7.9	7.8	7.9	7.8	7.8
$FeCO_3+O_2$ 1949	7.6	7.6	7.7	7.7	7.8	7.9	8.0	8.1	7.9	8.0	7 9	7.9	7.9	7.8	8 0	7.9	7.9	7.9	7.7	7.7	7 9	7.8	7 9	8.0	7.9	7.9	7.9	7.9
$FeCO_3$ 1922	7.0	6.9	7.4	7.7	7.7	7.8	7.6	7.7	7.7	7.7	7 8	7.7	7.7	7.8	7 7	7.9	7.9	7.9	7.9	7.9	7 7	7.8	7 7	7.9	7.9	7.7	7.7	7.7
$FeCO_3+O_2$ 1922	7.0	7.1	7.9	7.7	7.7	7.7	7.7	7.8	7.6	7.7	7 7	7.6	7.6	7.6	7.7	7.9	7.9	7.9	7.9	7.9	7 6	7.8	7 6	7.9	7.9	7.9	7.9	7.9
Sandstone	6.2	5.3	5.0	5.1	5.2	5.2	5.8	6.1	6.0	6.1	6 1	6.1	6.0	6.0	5 8	5.8	5.8	5.8	5.9	5.9	5 8	5.8	5 8	6.1	6.1	6.1	6.1	6.1
Sandstone+O_2	6.6	5.5	5.0	5.1	5.2	5.2	5.8	6.1	6.1	6.2	6 3	6.5	6.4	6.4	5.7	5.9	5.9	5.9	5.9	5.9	5.7	5.7	5 7	6.1	6.2	6.2	6.1	6.1

*A duplicate sample of each material was aerated to determine effects of added oxygen. Temperature maintained between 82° and 84° F.

TABLE 3 *Effect of Lower Kittanning overburden materials on the pH of distilled water*

Date of pH test	Jan. 18	(1952) 25	Feb. 8	16	22	29	Mar. 7	14	21	28	Apr. 4	11	18	25	May 2	9	16	23	30	June 6	13	20	27	July 4	11	18	25
Overburden Material*																											
FeS_2	2.3	2.1	1.8	1 7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.7	1.8	1.7	1.6	1.6	1.7	1 6	1.7	1.7	1.6	1.4	1.3	1.4	1.4	1.4	1.3
FeS_2+O_2	2.1	2.8	2.8	2.7	2.8	2.7	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.6	2.4	2.6	2.6	2.4	2.6	2.6	2.6	2 5	2.3	2.5	2.4	2.4	2.4
Cal. Shale	7.0	7.3	7.9	7 9	7.9	7.9	8.0	7.9	8.0	8.0	7.8	7.7	7.8	7.8	7.7	7.8	7.7	7.8	7.8	7.7	7.7	7 7	7.7	7.7	7.7	7.7	7.7
Cal. Shale+O_2	7.4	7.4	7.8	7 7	7.8	7.8	7.8	7.8	7.9	7.8	7.8	7.8	7.8	7.8	8.0	8.0	8.0	7.9	7.9	7.9	7.9	7 9	7.9	7.8	7.8	7.9	7.8
# 5 Coal	4.5	4.1	3.6	3 5	3.4	3.4	3.4	3.4	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3 1	3.0	3.0	3.0	2 9	2.9	2 9	2.9	2.9	2.9
# 5 Coal+O_2	4.9	4.8	4.6	4 7	4.7	4.8	4.9	4.9	4.6	4.5	4.5	4.6	4.5	4.5	4.4	4.5	4.5	4 5	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Carb. Shale	4 7	5.1	6.1	6 2	6.1	6.1	6.3	6.4	6.3	6.3	6.2	6.2	6.2	6.2	6.1	6.2	6.2	6.2	6.1	6.2	6.1	6.1	6.2	6.1	6.1	6.1	6.1
Carb. Shale+O_2	5.2	5.2	5.8	6 5	5.7	5.6	5.8	5.8	6.1	6.2	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	5.9	5.9	5.7	5.8	5.7	5.7	5.7
Blue Shale	7.7	7.6	7.9	7 9	7.9	7.8	8.0	8.0	8.0	8.0	7.7	7.8	7.8	7.8	7.7	7.8	7.7	7.7	7.6	7.6	7.8	7 8	7.9	7.8	7.9	7.9	7.9
Blue Shale+O_2	7.5	7.4	8.0	8.0	8.0	7.9	7.9	7.9	8.0	8.0	7.9	8.0	8.0	8.0	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7 9	7.9	7.9	7.9	7.9	7.9
$FeCO_3$ 1949	7.1	7.2	8.1	8 1	8.2	8.2	8.2	8.2	8.3	8.2	8.0	8.0	8.0	8.2	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8 2	8.2	8.1	8.1	8.1	8.1
$FeCO_3+O_2$ 1949	7.3	7.3	7.9	7 9	7.9	7.8	8.0	8.0	8.1	8.0	7.9	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8 0	8.1	8.1	8.1	8.1	8.1
$FeCO_3$ 1922	7.1	7.3	7.9	8 0	8.1	8.0	8.1	8.0	8.2	8.2	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8 4	8.4	8.4	8.4	8.4	8.4
$FeCO_3+O_2$ 1922	7.3	7.5	8.2	8 2	8 2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.1	8.1	8.1	8 1	8.1	8.1	8.2	8 2	8.3	8.3	8.3	8.3	8.3
Sandstone	4.1	4.1	3.8	3 7	3 6	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3 5	3.4	3.5	3.5	3.5	3.5
Sandstone+O_2	4.2	4.3	4.2	4.3	4 3	4.4	4.4	4.4	4.3	4.3	4.3	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.3	4 3	4.3	4 4	4.5	4.5	4.5	4.5	4.5

*Overburden material collected from same highwall used in experiment of table 2.

within any one district, extreme variations of pH, plant toxicity, soil structure and texture may occur; in some instances these variations may be present on an area no larger than one acre. Sometimes the variations are due to differences in the geologic strata, whereas in others it may be due to the method of stripping.

Research conducted by personnel of the Central States Forest Experiment Station indicates that the textural classification of Ohio spoil was ten percent sand, sandy shales and sandstones, about 42 percent silty shales and loams and 48 percent clay and limestone. The last-named textural type was found largely in Belmont, Harrison, and Jefferson Counties. Less than four percent of the spoil material in Ohio was classed as toxic, six and one-half percent as marginal, 47 percent acid, and slightly more than 40 percent calcareous.

Production by seams during 1956 was 986,593 tons of numbers four and four A, 1,294,228 tons of number five, 3,104,871 tons of number six, 9,825,808 tons of numbers eight and eight A, and 2,777,504 tons of number nine. (The figures given here are approximate, since some operators report total tonnage for as many as three or four seams with no individual breakdowns.) During the same year, 44 percent of the coal produced by strip mining came from the three counties mentioned above, an area with considerable limestone, marly clay, and calcareous shale overburden (Ohio Dept. of Industrial Relations, 1956).

EFFECT OF OVERBURDEN MATERIALS ON THE pH AND FERTILITY OF LAKE WATER

Water supply for the impoundments in the strip lands results from run-off and springs or in some instances as overflow from flooded streams, the latter occurring when the stripping is done on lower coal seams in the valleys.

The chemical condition of the impounded water, especially the pH, as reported in this paper is largely the result of the reactions of three or four materials found in the overburden or the coal seam. Due to the youthfulness of these impoundments, the small amounts of organic matter present probably exert little influence on pH. The acid produced by the organic matter is of minor significance to the aquatic organisms except perhaps when the critical pH is reached for a particular species. Grading operations and extent of vegetative cover on the watershed can be influential, however, in controlling the rate of oxidation and release of certain acidic materials.

Overburden materials having important effects on the pH of water include acid and marly clays, sandy shale, sandstone, limestone, siderite ($FeCO_3$) and marcasite (FeS_2). Siderite, commonly called iron carbonate, occurs in abundance as various sized concretions in layers above the number five or Lower Kittanning coal seam. Marcasite is commonly called iron sulphide, "gob" or iron pyrite, and may occur as layers one to five in. thick in the coal seam or as crystals distributed throughout the overburden. Actually, pyrite differs from marcasite in that the latter alters much more readily to melanterite ($FeSO_4 \cdot 7H_2O$) and limonite ($Fe_2O_3 \cdot nH_2O$) upon oxidation. Of the group of overburden materials tested under laboratory conditions, marcasite produced a pH that would seriously affect the water and the succeeding ecological events. Very small amounts of marcasite crystals in shale may produce relatively acid substrate in contrast to a nearly neutral substrate in their absence. The deleterious effects of marcasite are often increased by operational activities such as disposing of the waste "gob" somewhere on the watershed and leaving it uncovered. Frequently the "gob" may be gleaned from the coal and left in the bottom of a "dry" pit. Upon oxidation, the toxic wastes are carried from the pit into nearby streams or impoundments by run-off. Other materials such as the calcareous shale, marly clay, limestone and siderite tend to buffer, to a degree, the acidity produced by marcasite bearing material. The former materials tend to produce a neutral to slightly alkaline pH.

The chemical reactions of the overburden materials tested are as follows:

Marcasite (FeS_2)—alters to ferrous sulfate ($FeSO_4$) and sulfuric acid (H_2SO_4) and later to hydroxide pseudomorph such as limonite ($Fe_2O_3 \cdot nH_2O$) or melanterite ($FeSO_4 \cdot 7H_2O$) (Kraus, Hunt and Ramsdell, 1936). (A pseudomorph results from chemical alterations such as hydration or oxidation while retaining its external features).

Siderite ($FeCO_3$)—forms a pseudomorph after limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) and usually contains some limestone ($CaCO_3$) and/or rhodocrosite ($MnCO_3$). Chemical decomposition products are limonite, hematite (Fe_2O_3) a micaceous oxide, and magnetite (Fe_3C_4).

Limestone ($CaCO_3$)—occurs in calcareous shales and marly clays or as a layer one to several feet in thickness in the overburden of the Harrison-Jefferson-Belmont County region. Contained in the same material may be varying amounts of magnesium, iron and manganese which may replace the calcium. Resulting chemical changes produce the pseudomorph dolomite ($CaMg(CO_3)_2$) which is a carbonate of calcium and magnesium in a ratio of one to one.

TABLE 4

Effect of Lower Kittanning overburden materials on the pH of distilled water

Date of pH reading	Jan. 23	(1953) Feb. 30	Feb. 6	Mar. 13	Mar. 20	Mar. 27	Apr. 6	Apr. 13	Apr. 20	Apr. 27	May 3	May 10
Overburden Material*												
FeS_2	1.4	1.8	1.8	1.8	1.6	1.7	1.8	1.8	1.7	1.7	1.8	1.8
FeS_2+O_2	2.4	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.6	2.6
Cal. Shale	7.3	7.4	7.5	7.5	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Cal. Shale+O_2	7.4	7.5	7.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
# 5 Coal	3.2	3.5	3.3	3.3	3.3	3.3	3.2	3.3	3.3	3.3	3.3	3.3
# 5 Coal+O_2	3.3	4.4	4.5	4.5	4.4	4.5	4.4	4.5	4.5	4.5	4.5	4.5
Carb. Shale	5.3	5.0	5.1	5.1	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Carb. Shale+O_2	4.6	4.6	4.6	4.6	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Blue Shale	7.2	7.1	7.1	7.1	7.2	7.2	7.2	7.2	7.2	7.2	7.1	7.1
Blue Shale+O_2	6.7	7.3	7.3	7.3	7.5	7.5	7.5	7.5	7.5	7.5	7.4	7.4
$FeCO_3$ 1949	7.9	7.6	7.7	7.7	7.7	7.7	7.7	7.6	7.6	7.6	7.7	7.7
$FeCO_3+O_2$ 1949	7.6	7.8	7.8	7.8	8.2	8.1	8.1	8.1	8.1	8.1	8.2	8.2
$FeCO_3$ 1922	7.6	7.8	7.8	7.8	7.7	7.7	7.7	7.7	7.8	7.8	7.7	7.7
$FeCO_3+O_2$ 1922	7.6	7.7	7.7	7.7	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Sandstone	4.3	4.4	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Sandstone+O_2	4.6	4.5	4.6	4.6	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2

*Same material used in experiment of table 3, after drying for five months. Water added January 16, 1953.

Chemical reactions occurring may be the oxidation of marcasite (FeS_2) to ferrous sulfate ($FeSO_4$) and sulfuric acid (H_2SO_4). The carbonates, limestone ($CaCO_3$) and siderite ($FeCO_3$), tend to react with the water to form calcium hydroxide ($Ca(OH)_2$) and carbon dioxide (CO_2) which acts upon the $FeSO_4$ to from ferrous hydroxide ($Fe(OH)_2$) and calcium sulphate ($CaSO_4$). The $Fe(OH)_2$ forms flakes while the calcium sulphate ($CaSO_4$) is relatively insoluble and both precipitate out. The sulfuric acid (H_2SO_4) ionizes readily and produces a great number of free hydrogen ions, increasing the pH considerably. The carbonate ($CaCO_3$) acts upon sulfuric acid to produce carbonic acid (H_2CO_3) and $CaSO_4$, with the former breaking down into water and carbon dioxide.

In recent years Temple and Koehler (1954) have studied the role of certain bacteria in the production of acid mine water. The two bacteria *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* have been found to have important roles in sulphur and iron oxidation respectively. Apparently, considerably more research is needed before their significance as agents is completely understood.

The fertility of the spoil material found in the Allegheny Formation from above the number five coal seam is rather low as revealed by results of fifteen samples analyzed by the Dept. of Agronomy, the Ohio State University (table 1). Samples were collected from the surface six inches of spoil that had been deposited by strip mining in 1919 (Riley, 1947).

Recent analysis of spoil samples following grading operations on weathered spoils, similar in age to those discussed in this paper, indicate that the available phosphorous and potash tend to leach several feet down into the spoil material. Thus, these nutrients would be a factor influencing the chemical condition of the water during the early years, but would be of greatest significance to vegetation on the watershed at a later time.

EFFECTS OF OVERBURDEN MATERIALS ON THE pH OF WATER UNDER LABORATORY CONDITIONS

Duplicate samples of eight different kinds of overburden materials, and number five coal, were collected from a highwall within the Allegheny Formation in Wayne Twp., Tuscarawas County, Ohio. Two samples of iron carbonate ($FeCO_3$) were collected from spoil that had weathered for 28 and 30 yr, respectively. During the first test series, January 11, through August 28, 1950 (table 2), 100 gm of each overburden material were crushed to two mm mesh size and placed in battery jars containing 2500 cm^3 of distilled water (pH 6.5). Each sample of overburden material was checked for purity. The water level was kept constant throughout the entire period of eight months and the first test, in which a Beckman pH meter was used, was made 24 hr after initiation of the experiment and subsequently at intervals of one week. The top of the jar of one sample of each overburden material was covered with a cellophane cap to simulate conditions on the bottom of a strip mine pond. The duplicate sample of each material was aerated, using a small air pump, to simulate conditions where the water level covers only part of the coal face or acid overburden material and where additional oxygen may tend to increase the rate of oxidation and consequent release of acid.

Following the first series of tests, a second series was run from January 18, through July 25, 1952 (table 3), and from January 23, through April 10, 1953 (table 4). During the second experiment, 20 gm of each overburden material, two mm mesh, were placed in battery jars containing 500 cm^3 of distilled water (pH 6.06). The temperature for all test solutions ranged from 82° to 84° F. During the period of the second test series (1952–1953), the water was completely removed from each sample on August 2, 1952, and the remaining solids permitted to air dry until January 23, 1953, when the tests were resumed for three and one-half months.

Data resulting from the two series of tests indicate the effect of the marcasite (FeS_2) and other materials of the overburden on the pH of distilled water (tables 2, 3 and 4). During the first test series the marcasite lowered the pH of distilled water from 6.5 to 3.2 and 3.4 in 24 hr. Recent tests have indicated this extreme pH change occurs during the first hour after the marcasite is placed in the water. It is interesting to note that when completely fresh marcasite is removed from the interior of a solid "gob ball," or nodule, where there is little chance of the bacteria *T. thiooxidans* and *T. ferrooxidans* being present, this same rapid reduction in pH occurs. It is evident that, at least initially, the release of acid is largely the result of a chemical reaction which takes place without the presence of bacteria.

In the second test series, of seven months duration, using less solute and solvent (20 gm of marcasite and 500 cm^3 of water), the pH of the solution ranged between 1.3 and 2.8 (table 3). After testing the second series for seven months, then air drying the materials in each sample for approximately five and one-half months, tests were resumed for a period of three and one-half months during which the pH ranged between 1.4 and 2.6 (table 4). Only very slight differences in pH were registered as a result of aeration.

Of the remaining overburden materials used, from the Allegheny Formation, the pH measurements of three samples indicate they may contain a sufficient amount of marcasite to be a factor in depressing the pH (tables 2, 3, and 4). The samples of number five coal produced fairly acid conditions in both test series. In the first coal series, pH tests ranged from 4.8 to 7.0 while in the second series the pH ranged from 2.9 to 4.9. The first test series of carbonaceous shale gave a

TABLE 5

Plankton of six coal strip mine lakes

Age of lakes	22 yr	22 yr	20 yr	10 yr	1 yr	1 yr
Spoil district	III	III	IV	IV	IV	III
Dissolved O_2 ppm	9.1	9.1	10.7	7.7	6 9	8 1
CO_2 ppm	26.1	23.0	0	204.0	0	125.8
pH	5.5	6.5	7.0	4.0	7.0	4.0
Animals						
Protozoa						
Difflugia spp.		C				
Dinoflagellate spp.		A				
Rotifera						
Anurea spp.			C		R	
Cathypna spp.		C				
Synchaeta spp.			R			
Unknown spp.				R		
Arthropoda						
Cyclops spp.		C				
Plants						
Chlorophyceae						
Ankistrodesmus		R				
Chaetosphaeridium spp.		R				
Closterium spp.		R			R	
Cosmarium spp.	R	A				
Desmids	R	A	A	R		
Gonatozygon spp.		R				
Gonium spp.		R				
Hormidium spp.			A			
Microthamnion spp.		R				
Mougeotia spp.		R				
Oedogonium spp.		C				
Pleurotaenium spp.	R	A				
Spirogyra spp.		R				
Zygogonium spp.	R					
Bacillarieae						
Cymbella spp.			R			
Diatoma spp.		R		R		
Eunotia spp.				R		
Gomphonema spp.		R				
Navicula spp.	R	R	A	A		A
Synedra spp.			C			
Tabellaria spp.		R				
Euglenophyceae						
Euglena spp.			A	R		
Trachelomonas spp.			R			
Myxophyceae						
Arthrospira spp.			R			
Oscillatoria spp.			C			
Unknown spp.				R		
Dinophyceae						
Peridinium spp.		A				
Chrysophceae						
Dinobryon spp.					A	
Heterokontae						
Tribonema spp.			C			

(A) Abundant. (C) Common. (R) Rare.

pH range from 5.9 to 7.9 while in the second series the range was 4.4 to 6.4. Tests of the lower Freeport sandstone gave a pH range for the first series of 5.0 to 6.6 while in the second series the range was 3.4 to 5.2. The variation in pH between materials from the same overburden used in the two test series could be attributable to variation in amount and concentration of marcasite present.

The other three samples tested, namely hard calcareous shale, soft blue shale, and siderite (1922 and 1949), produced a pH consistently neutral to slightly alkaline. In the case of siderite, samples of two different ages were used; one sample was taken from a concretion that had weathered since 1922, the other from a highwall where it had been sealed off completely from air.

TABLE 6

Results of test netting a six acre Ohio strip mine lake

Species	Average length (standard) in inches	Length maximum (in.)	Length minimum (in.)	Total number measured
Sucker	13.1	16.0	9.5	52
Bluegill	5.5	10.0	4.0	43
Largemouth black bass	9.3	13.0	6.0	16
Brown bullhead	8.5	10.0	7.0	8
Warmouth bass	6.0	6.0	6.0	3

As a result of the series of tests, four overburden materials of the Allegheny Formation, namely coal, sandstone, carbonaceous shale and marcasite, appeared to be responsible for the production of the acid condition associated with water impounded in the coal strip lands. In each instance, marcasite (FeS_2) is the causative agent. In the first three overburden materials discussed above, this mineral is present in varying degrees while "gob" is almost entirely marcasite.

Prior to 1952, I observed a total of nine buried "gob" dumps on the watersheds of a similar number of ponds. Each had been buried with an average of three ft of nontoxic spoil material and each pond contained water suitable for a variety of plant and animal life. I have observed lakes with a concentration of "gob" on the watershed, having water with a pH of 2.4, while 100 ft away where no concentration of "gob" existed, the pH of the water tested 6.1 (Riley, 1952). In recent years the burial of the "gob" with nontoxic spoil material or submergence of "gob" and toxic carbonaceous shales by impoundment have proven to be very practical and economical methods of eliminating the production and release of acid. By eliminating through burial or submergence those overburden materials containing concentrations of marcasite, the acid released by the marcasite contained in other overburden materials is buffered sufficiently to be inconsequential to animal and plant life.

THE EFFECT OF ACID RELEASED FROM OVERBURDEN MATERIALS ON FISH

At the conclusion of the pH tests on the first series of overburden materials, one bluegill fingerling (*Lepomis m. macrochirus*) was placed in each water sample. The individuals placed in the marcasite samples, pH 2.4 and 2.6, were dead in exactly 20 min, while those individuals in all other samples were still in excellent condition at the end of 96 hr. The mucus on the fingerlings in the marcasite began to coagulate in four min; the individual in the coal sample, (pH 4.9), appeared to suffer no ill effects. In additional tests using the common shiner (*Notropus cornutus frontalis*), individuals in the marcasite samples were dead in 22 min, while those in the remaining samples appeared to be in good condition at the end of 96 hr. Even aeration of the water containing the marcasite failed

to increase the survival time for either of the two species of fish. While it may appear that death resulted from coagulation of the mucus on the gills, thus impairing respiratory efficiency, one cannot be sure. Temperature, dissolved oxygen, water hardness, species of fish used, and a host of other factors might have been responsible. Recent work by Doudoroff and Katz (1950) indicate that under otherwise favorable conditions water having a pH range of 5.0 to 9.0 is not lethal for most fully developed fresh water fishes. These authors also indicate that a more extreme pH, perhaps below 4.0, can be tolerated indefinitely by resistant species. However, tolerance to low pH values by a desirable species of fish is only part of the problem in management of such waters; there is also the effect of the low pH on the entire biota and the influence on the production of food for the desirable species.

SURVEY OF AQUATIC LIFE IN COAL STRIP LAND LAKES AND PONDS

Thirteen lakes and ponds were surveyed in Columbiana, Harrison, Jefferson, Tuscarawas, Muskingum, and Jackson Counties. The density of the flora of the lakes was found to be dependent on age, water depth, fertility, spoil type, pH and degree of slope of the lake basin. One very shallow lake in Muskingum County, for example, contained a large amount of the white water lily (*Nymphea tuberosa*) covering 90 percent of the water surface. Emergent aquatics included the narrow-leaf cattail (*Typha angustifolia*), common cattail (*T. latifolia*), arrowhead (*Saggitaria latifolia*), fox sedge (*Carex vulpinoidea*), sharp-fruited rush (*Juncus acuminatus*), soft rush (*J. effusus*), burreed (*Sparganium* spp.), and bulrush (*Scirpus cyperinus*). Submerged aquatics included curly pond weed (*Potamegeton crispus*), needle spike rush (*Eleocharis acicularis*), water-starwort (*Callitriche* spp.), common waterweed (*Elodea canadensis*), coontail (*Cerataphyllum* spp.) (Muenscher, 1944), and the alga (*Chara* spp.) (Smith, 1933). A moss (*Drepanocladus fluitans*) (Conard, 1944) was found in one lake in Tuscarawas County. Curly pond weed was found in two alkaline lakes (pH 7.5) in Jefferson County while coontail and water weed were found in two alkaline lakes of Harrison and Jefferson counties. Within the 13 lakes studied narrow-leaf and common cattail were by far the most common vascular plants.

Plankton samples were collected from six of the 13 lakes ranging from one to 22 yr old to determine the variety of microorganisms associated with this type of aquatic environment. Identification of the samples revealed a total of seven classes of algae including 29 genera, two Protozoa, four Rotifera and one Arthopoda. The samples were collected on May 1, 1948; thus, the data merely reveal what was present on that particular day, and it should not be inferred that this sample is representative of organisms found throughout the year. Table 5 reveals the various genera of plankton identified, the age of the body of water, pH, dissolved oxygen and free carbon dioxide. Plankton counts indicated a scarcity of numbers when compared to those in many nonstrip mine impoundments. It is interesting to note that one 22-yr-old lake, with a slightly acid pH (6.5), had the greatest number of genera of algae (17), two Protozoa, one Rotifera and one Arthropoda. In an earlier study of this same lake 14 species of aquatic insects were collected and identified (Riley, 1947). They included the following Coleoptera: (*Berosus striatus*), (*Enemidotus edentulus*), (*Enemidotus muticus*), (*Coptotomus interrogatus*), (*Dineutes americanus*), (*Dytiscus fasciuentris*), (*Tropisternus* spp.) (Blatchley, 1910); order Hemiptera, (*Aretocorive parshley*), (*Belostoma fluminea*), (*Pelacoris femoratus*), (*Sigara atopodonta*) (Blatchley, 1926); order Odonata, (*Aeshna sitchensis*), (*Aeshna* spp.), and (*Arglatibialis* spp.) (Wright and Peterson, 1944).

Within the 13 lakes studied in Ohio, a total of 15 species of fish were collected and identified. (Species were collected and identified by test netting, fly and bait casting and personal observation of catch records by responsible lake owners.) Included within this group were the bluegill, largemouth black bass (*Micropterus*

salmoides), white crappie (*Pomoxis annularis*), black crappie (*P. nigromaculatis*), brown bullhead (*Ictalurus n. nebulosus*), smallmouth black bass (*Micropterus d. dolomieu*), channel catfish (*Ictalurus lacustris punctatus*), gizzard shad (*Dorosoma cepedianum*), warmouth bass (*Chaenobryttus gulosus*), carp (*Cyprinus carpio*), redhorse sucker (*Moxostoma* spp.), common white sucker (*Catostomus c. commersonnii*), horny head chub (*Hybopsis biguttata*), blue catfish (*Ictalurus furcatus*) and the common shiner (Hubbs and Lagler, 1949). In addition the brown trout (*Salmo trutta*), rainbow trout (*S.gairdneri*), yellow perch (*Perca flavescens*) and redear sunfish (*Lepomis microlophus*) have been introduced in four coal strip mine lakes of Harrison County. The first three have been successful in the "stock and take" program but did not reproduce while redears have reproduced prolifically.

During the fall of 1950, one six-acre unmanaged lake in Jefferson County was test-netted for a period of 96 hr with the nets being lifted every 24 hr. Five species, including a total of 122 individuals, were netted. Included were 52 white and red horse suckers, 43 bluegills, 16 largemouth black bass, eight brown bullheads and three warmouth bass (table 6).

No information was available on the original stocking, such as species composition, size of stock and date of stocking; thus, the data are not considered too significant.

Other data concerning populations and size included largemouth black bass, 27 in., bluegills, nine in., brown bullheads, 11 in., smallmouth black bass, 20 in., common suckers, 16 in. and channel catfish, 15 lb from a lake in Muskingum County. In one Jackson County strip mine lake largemouth black bass, 22.5 in., gizzard shad, ten in. and bluegills, eight in. were removed.

During October, 1947, a one-acre strip mine lake in Tuscarawas County (pH 5.5 to 6.5) was stocked with 889 bluegills (1 in.–2 in.) and 134 largemouth black bass (1 in.–3 in.). The lake was observed approximately twice per month; bluegills reproduced during the spring and summer of 1948 while bass were not observed after ice formed on the lake in November, 1948. In 1949, 100 bluegills were removed averaging six in. in length (5.5 in.–6.5 in.) while 85 were removed during May and June, 1950, averaging the same as in the former year. In 1951, 175 bluegills were removed averaging 4.5 in. (3.5 in.–6.0 in.).

An additional 500 bass (2.5 in.–4 in.) were stocked in the same lake in October 1952 and 500 again in August, 1955 (2.5 in.–3.5 in.). The first bass spawn were observed in May, 1954. Since the summer of 1955, bass (10 in.–18 in.) and bluegills (5.5 in.–9.5 in.) have been harvested from this lake. During the summer of 1958, 114 bluegills were removed within the latter size range.

Amphibians collected and identified included the common toad (*Bufo americanus*), green frog (*Rana clamitans*), leopard frog (*R. pipiens*), pickerel frog (*R. palustris*) and the cricket frog (*Acris crepitans*) (Walker, 1946). Eighty bullfrog tadpoles (*R. catesneiana*) were stocked in one Ohio strip mine pond in May, 1951. Three adult bullfrogs and numerous tadpoles were observed in the same pond in June, 1958. Of the amphibians the green frog was by far the most abundant.

Three species of reptiles were identified including the snapping turtle (*Chelydra serpentina*), painted turtle (*Chyrsemys belli marginata*), and the water snake (*Natrix sipedon*) (Pratt, 1935).

Fifteen species of waterfowl and eight species of shorebirds were observed on or around strip mine impoundments. Twelve of the 15 waterfowl species were observed on two small lakes in Tuscarawas County. Species observed and identified included the Canada goose (*Branta c. canadensis*), common mallard (*Anas p. platyrhynchos*), common black duck (*Anas rubripes*), gadwall (*Anas strepera*), baldpate (*Mareca americana*), blue-winged teal (*Anas discors*), wood duck (*Aix sponsa*), red head (*Aythya americana*), canvasback (*Aythya valisineria*), American golden-eye (*Glaucionetta clangula americana*), bufflehead (*Glaucionetta albeola*), hooded merganser (*Lophodytes cucullatus*), American merganser (*Mergus merganser*

americanus), horned grebe (*Colymbus auritus*) and the pied-billed grebe (*Podilymbus p. podiceps*). Shorebirds included the green heron (*Butorides v. virescens*), great blue heron (*Ardea herodias*), American bittern (*Botaurus lentiginosus*), woodcock (*Philohela minor*), Wilson's snipe (*Capella gallinago delicata*), killdeer (*Charadrius v. vociferus*), greater yellow-legs (*Totanus melanoleucus*), and lesser yellow-legs (*Totanus flavipes*) (Peterson, 1939).

During the migratory seasons fairly large populations of waterfowl were observed on the strip mine lakes. In September, 1949, 43 mallards were observed on seven acres of water, and in October, 100 wood ducks were identified on the same area. During August, 1949, six wood ducks were observed on a 13 acre strip mine lake. Waterfowl were present in greatest numbers during the migratory seasons although three species were found nesting around or near strip mine ponds. During 1948 and 1949, two broods of mallards were observed on a Jefferson County pond; one brood of blue-winged teal was observed on a pond in Harrison County during 1955 and 1956; a brood of wood ducks in 1956 and one brood of mallards in 1956, 1957 and 1958, all in the latter county.

During the summer of 1949, 18 nests of the red-wing black bird (*Agelaius p. phoeniceus*) containing young were observed around one seven-acre lake.

Mammals living in or near the aquatic strip mine habitats were the muskrat (*Ondatra z. zibethica*), beaver (*Castor c. canadensis*), raccoon (*Procyon l. lotor*), and mink (*Mustela v. vison*) (Bole and Moulthrop, 1942). Both the muskrat and raccoon were present in fairly large numbers with the latter utilizing such areas in search of food. The muskrat was found in nearly every type of strip mine lake or pond and the numerous paths observed by the investigator indicated considerable inter-pond movement. In recent years the beaver has become very numerous in strip mine ponds in Columbiana County. The acidity of the water seemed to have little effect on the use of such areas by the muskrat. This species was inhabiting ponds having a pH as low as four. Dens were usually present in lakes having steep sided basins while houses were more numerous in shallow ponds less than two ft in depth. Bank dens were usually very shallow, and in the spring usually caved in, possibly due to the spoil material being fairly loose. Fifteen and 13 dens, respectively, were observed along 200 ft of shoreline of two lakes in Harrison County. Two landowners in Muskingum County harvested 40 muskrats from 13 acres of water and 50 from six acres in 1948.

SUMMARY

1. The open-pit method of coal mining initiated in Ohio in 1914 had affected approximately 124,115 acres of land in 27 counties as of January 1, 1957.

2. As a result of the stripping operations, hundreds of acres of water were impounded in final cuts, behind haul roads across old fields or between the spoil banks. Within the strip lands, aquatic habitats included marshes, ponds and lakes. They ranged in age from one to 45 years and up to 13 acres in surface area. The extreme was one lake of 100 acres. Depths usually were less than 25 ft; however, one had a depth of 40 ft.

3. Watersheds ranged from one to 30 acres and had from 25 to 100 percent of the spoil surface covered by vegetation. Since the geological strata or overburden above the coal seams varied throughout the 27 counties, the physico-chemical conditions of the watershed soil and impounded water were greatly modified, resulting in ecological conditions quite different from those in noncoal strip mine ponds.

4. The type of soil making up the lake basin varied from clays in final cuts to clay, silty or sandy shales, sandstones and limestones of inter-spoil basins to undisturbed soil where lakes were formed as a result of a haul road being constructed across a valley. Clay provided an almost impervious basin, thus reducing the possibility of water loss through leakage.

5. Stripping methods, depending on the type of machine used in overburden removal, influenced the physico-chemical complex of the impounded water. Stripping shovels usually produced well mixed spoil material for the watershed while draglines and scoops tended to remove the acid carbonaceous shales from immediately above the coal seam last and place them on top of the less toxic materials of the watershed.

6. The textural classification of the spoil material forming the watersheds of strip land ponds and lakes has been categorized as ten percent sand, sandy shales and sandstone, about 42 percent silty shales and loams and 48 percent clay and limestone. Less than four percent of the spoil material was classed as toxic, six and one-half percent as marginal, 47 percent acid and slightly more than 40 percent calcareous.

7. Water supply for these impoundments usually came from run-off or from springs. Occasionally when the stripping was done in a valley, overflow from a nearby stream was the principal source. The pH, fertility, and productiveness of the impounded water was greatly influenced by the particular geological strata of the watershed. Watershed spoil removed from above coal seam four (Brookville) and eight (Pittsburgh) usually contained sufficient calcareous material resulting in water having an alkaline pH, while water flowing over spoil material from the other seams was usually acidic. Productiveness of the pond was influenced not only by pH and fertility of the spoil, but also by the rate of disintegration of spoil, leaching, amount of silting and age of the impoundment.

8. Fifteen soil samples from number five spoil (27 years old) in the Tuscarawas County area were analyzed. The pH of the soil samples ranged from 3.5 to 7.5. Tests for active calcium, available phosphorous and available potassium were generally low.

9. Overburden materials deposited as spoil and influencing the pH included acid and marly clay, sandy, silty or carbonaceous shale, sandstone, limestone, siderite ($FeCO_3$) and marcasite (FeS_2). Limestones, various shales and sandstone produced a pH range from medium acid to slightly alkaline.

10. Laboratory tests of eight different overburden materials above the number five coal seam, and including the coal itself, indicated that marcasite (FeS_2) was largely responsible for the toxic condition present in many ponds associated with this coal seam. Other materials releasing considerable acid and consequently producing a fairly low pH were number five coal and sandstone associated with this seam. The various shales and siderite ($FeCO_3$) produced a pH range from medium acid to slightly alkaline. Aeration of the control sample did not produce any great differences in pH.

11. At the conclusion of the first series of tests on overburden materials, one bluegill fingerling was placed in each sample. Those individuals placed in the marcasite samples (pH 2.4 and 2.6) were dead in 20 min, while those in the remaining samples appeared to be in excellent condition at the end of 96 hr. The mucus on the bluegills, in the marcasite samples, coagulated in four min and their erratic behavior indicated respiratory difficulties and possible irritation of the skin. A second species, the common shiner, was used and death resulted in exactly 22 min in the marcasite samples. In the remaining samples no difficulties were apparent at the end of 96 hr. Aeration of one sample of marcasite did not increase the survival period for the test specimen.

12. In 13 strip mine lakes surveyed in Columbiana, Harrison, Jefferson, Tuscarawas, Muskingum, and Jackson Counties, narrow-leaf and common cattail and arrowhead were the most abundant species of vascular plants. Submergent aquatics included five species of vascular plants, and one species of moss.

13. Studies of plankton samples collected from six ponds ranging in age from one to 22 yr included two genera of Protozoa, four of Rotifera, 29 of algae and 15 Arthropoda consisting of 14 species of Insecta and one of Crustacea. Of the

six lakes from which plankton samples were collected, the most productive was a 22-yr-old lake associated with the number five coal seam having acid overburden materials.

14. A total of 15 species of fish were collected and identified within 13 lakes of six counties. Four species of frogs and one species of toad were found, while the bullfrog was introduced into one pond by the author. The snapping turtle, painted turtle and common water snake were identified as inhabitants of these aquatic habitats.

15. Fifteen species of waterfowl and eight species of shorebirds were observed either on the lakes or along the shore areas. The mallard, wood duck and blue-winged teal all were observed nesting on or near strip mine ponds in Harrison County.

16. Four mammals, all fur-bearers of importance, were inhabiting the marsh and pond areas. Of the four, the muskrat was the most numerous inhabitant and was taken in greatest numbers by trapping. Muskrat production based on trapping results for one final cut lake and one marsh in Muskingum County was three and 8.3 rats per acre.

17. A practical management measure to reduce the production and release of acid was burial of the more toxic materials. "Gob," coal gleanings and acid carbonaceous shale when buried under three feet of nontoxic materials released very little acid. Acid formation from these same materials, if in the bottom of the pit, was minimized by raising the water level well over the face of the coal seam and the carbonaceous shale immediately above the coal.

18. Vegetation, well adapted to the varied sites of the watershed, rapidly growing and producing an abundance of leaf litter also aided in reducing oxidation and the consequent release of acid. Black locust (*Robina pseudoacacia*) and sweet clover (*Melilotus* spp.), while not always as desirable to the landowner as other species, are adapted to a wider range of sites than most other plants. Both species were not only adapted to a variety of sites, but they grew very rapidly and provided a mat of organic matter over the spoil surface in a relatively short time.

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DRAINAGE OF THE TEAYS-STAGE MOUNT VERNON AND CAMBRIDGE RIVERS*

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The most important sources of ground water in Ohio are glacial outwash sand and gravel deposits in buried valleys. One of the primary objectives of the groundwater geologist in Ohio, therefore, is to locate and map the courses of these buried valleys.

Most of the data in this paper were collected by the author during a water-resources investigation in Licking County, Ohio, made by the U. S. Geological Survey in cooperation with the Division of Water, Ohio Department of Natural Resources. Altitudes of the bedrock surface were obtained from water-well records on file at the Ohio Division of Water, oil-well and gas-well records on file at the Ohio Geological Survey, and seismic refraction determinations made by the Geophysics Branch, U. S. Geological Survey.

Mount Vernon River

The Mount Vernon River, named by W. G. Tight in an unpublished article referred to by Clark (1902), was the second longest tributary to the Teays River, being surpassed in length only by the Marietta River described by Stout, Ver Steeg, and Lamb (1943, p. 57). The Mount Vernon River and its tributaries drained all of Coshocton, Franklin, Knox, and Licking Counties and parts of Ashland, Fairfield, Holmes, Muskingum, Pickaway, Richland, Tuscarawas, and Wayne Counties, Ohio. The river's headwaters were in the highlands of Wayne County near Burbank and West Salem and in Ashland County near Savannah. From its headwaters the Mount Vernon River flowed southwest past Wooster to Shreve, thence west past Big Prairie and Loudonville to Perrysville. From Perrysville the river flowed southwestward past Butler to Ankenytown, and thence south past Mount Vernon to the Knox-Licking County line. At the Knox-Licking County line, just north of Utica, the river swung west into Licking County, past Homer and Johnstown, and thence south past Jersey and Pataskala into Fairfield County. In Fairfield County, near Pickerington, the Mount Vernon was joined by a large tributary from the east, called herein the Cambridge River. From the confluence with the Cambridge River, the Mount Vernon River flowed west across the southeast corner of Franklin County past Canal Winchester and Groveport into Pickaway County where, near South Bloomfield, it joined the main stem of the Teays River (see fig. 1). From its headwater areas in Wayne and Ashland Counties to its junction with the Teays River in Pickaway County the Mount Vernon River was about 115 miles long.

North of Mount Vernon the drainage system of the Mount Vernon River was the same as that described for Stout, Ver Steeg, and Lamb's Groveport River (1943, p. 66). The bedrock walls and floor of the old valley were eroded by ice of the Pleistocene epoch, and glacial drift deposited by the ice now masks the valley for most of its length. Altitudes shown for the floor of the valley, therefore, are only approximate.

Altitudes on the bedrock floor of the Mount Vernon valley as determined from existing well data are 850 ft at Burbank, 840 ft at Wooster, 835 ft at Shreve, and 830 ft at Perrysville. Because of the thick cover of glacial drift and insufficient

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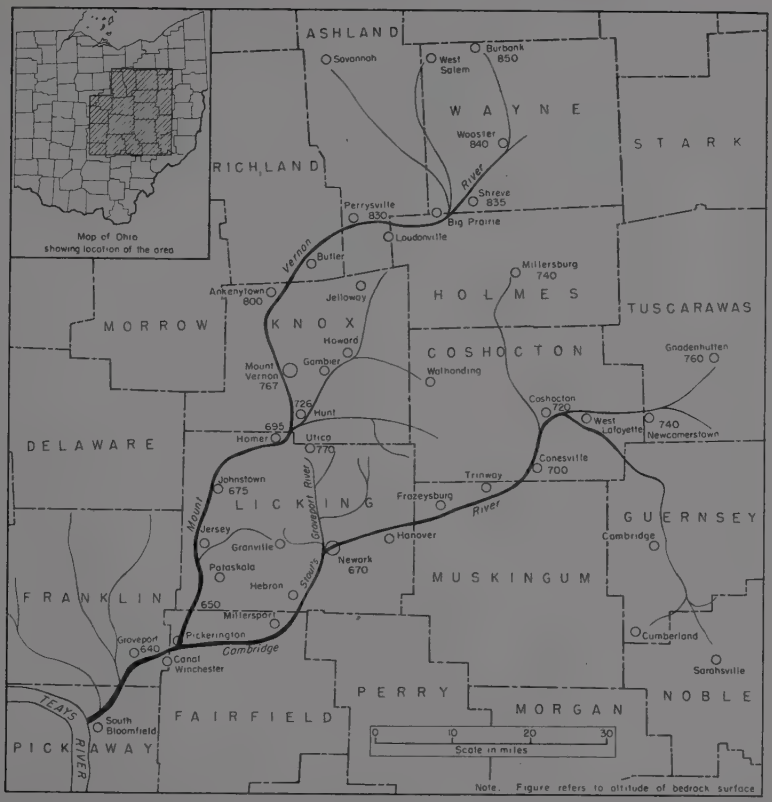

FIGURE 1. Map showing the courses of the Teays-stage Mount Vernon and Cambridge rivers.

well data, the author was unable to determine the altitude of the bedrock floor between Perrysville and Mount Vernon. Stout, Ver Steeg, and Lamb (1943), however, reported altitudes of 800 ft at Ankenytown and 767 ft at Mount Vernon.

About four miles south of Mount Vernon, the Mount Vernon River received a small tributary from the northeast. The drainage system of this small stream was the same as that described by Clark (1902, p. 3) as the principal course of Tight's Mount Vernon River. The tributary stream headed near Jelloway and flowed south to Howard, where it joined another stream whose headwaters were to the east near Walhonding. From their junction at Howard, these streams flowed southwest past Gambier to Hunt, where they joined the Mount Vernon River.

After receiving this small tributary from the northeast, the Mount Vernon River swung west and entered Licking County just east of Homer. Drillers' logs of water, oil, and gas wells show the altitude on the bedrock floor of the valley south from Mount Vernon to be 726 ft at Hunt and 695 ft near Homer. Seismic determinations made near Johnstown indicate that the altitude of the bedrock floor there is about 675 ft. Resistivity measurements and water-well records show the valley floor to be about 650 ft in altitude at the Licking-Fairfield County line.

Stout, Ver Steeg, and Lamb (1943, p. 66–67) thought the stream that flowed south from Mount Vernon entered Licking County near Utica. They state, "From Mount Vernon southward the course of the preglacial Groveport River is so rock bound as to be defined past Hunt, Utica, St. Louisville, and Vanatta to Newark. . . . " This concept is not consistent with present findings based on oil-, gas-, and water-well records on file at the Ohio Geological Survey and the Ohio Division of Water. These data reveal that a low, saucer-shaped drainage divide existed at an altitude of about 770 ft near Utica during Teays time.

Cambridge River

After passing into Fairfield County, the Mount Vernon River was joined by a large tributary whose headwaters were to the east near Cumberland in Guernsey County and Sarahsville in Noble County. From its headwaters the tributary stream flowed northwest past Cambridge to West Lafayette, where it was joined by a smaller tributary that rose near Gnadenhutten. This smaller tributary flowed southwestward past Newcomerstown and thence westward to West Lafayette. From West Lafayette waters from the confluence of these tributary streams flowed westward to a junction, near Coshocton, with a third tributary that headed near Millersburg in Holmes County. From this junction the main stream followed the present course of the Muskingum River past Conesville to Trinway. At Trinway the stream left what is now the Muskingum River valley and flowed west past Frazeysburg and Hanover to Newark. The course of the stream westward to Newark is the same as that described for the Teays-stage Cambridge River by Stout and Lamb (1938, p. 66). Stout, Ver Steeg, and Lamb, (1943, p. 65) state that the Cambridge River joined the larger Groveport River at Newark. As stated previously, no large Teays-stage stream flowed from the Utica area; however, the Cambridge River was joined at Newark by a small stream that headed near Utica and also by a small stream that had its headwaters near Granville.

In this paper the Cambridge River includes not only that part of the stream to the east of Newark but also the part that flowed south from Newark to Hebron and Millersport and thence west to its junction with the Mount Vernon River near Pickerington. Drillers' logs of wells show altitudes on the bedrock floor of this old valley to be about 740 ft near Millersburg, 760 ft near Gnadenhutten, 740 ft at Newcomerstown, 720 ft at Coshocton, 700 ft at Conesville, and 670 ft at Newark. From Newark to Pickerington altitudes on the bedrock floor of the Teays Stage valley are not known, as the area is covered by a thick mantle of glacial drift; however, from Newark to Hebron the valley is clearly outlined by the adjacent bedrock hills, and from Hebron to Pickerington the course of the Cambridge River may be readily deduced from available well data.

From Pickerington the Mount Vernon River flowed west past Groveport and then swung southwest into Pickaway County where it joined the Teays River. The altitude of the bedrock floor at Groveport is about 640 ft, but from Groveport southwest to the junction with the Teays River altitudes are undeterminable, as the valley of the Mount Vernon River was obliterated by a stream of the drainage system that followed the Teays.

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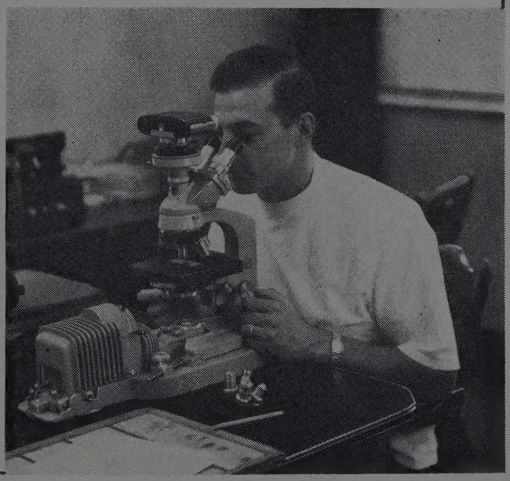

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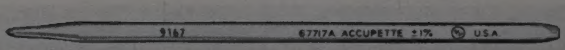

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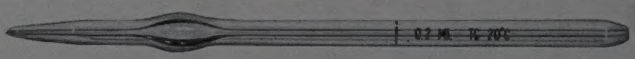

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S/P Accupettes are quality constructed—each piece of S/P glassware is individually calibrated to precise measurements. Graduations are permanent, amber-stained. Regular bore volumetric pipettes have guaranteed accuracy of ±1%; fine bore, bulk type Accupettes ±½% accuracy. All Accupettes have uniform wall strength which cuts down breakage common in funnel-shaped pipette tops. Accupettes are easy to clean, too.

No. 67717A—Accupette, regular bore without bulb

Cap., ml	Cap. lambdas	Each	12, each
0.01	10	$1.15	$0.95
0.02	20	1.12	.94
0.025	25		
0.04	40	1.15	.95
0.05	50		

No. 67717B—Accupette, fine bore with bulb

0.02	20	$1.10	$0.95
0.025	25		
0.05	50	1.25	1.05
0.1	100		
0.2	200	1.40	1.20
0.25	250		

Accupette—T.M. S/P, div. AHSC

For full details on any of your laboratory requirements, contact your local S/P office . . . the one source for all your laboratory supplies.

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PLAN TO ATTEND ____

The Sixty-Ninth Annual Meeting of

THE OHIO ACADEMY OF SCIENCE

to be held at

Antioch College, Yellow Springs, Ohio

April 21, 22, and 23, 1960